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PHYSICAL LABORATORY MANUAL

CHARLES F. ADAMS

UNIVERSITY OF CALIFORNIA

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PHYSICAL
LABORATORY MANUAL
FOR SECONDARY SCHOOLS

UNIV. OF
CALIFORNIA

REVISED EDITION

BY

CHARLES F. ADAMS, A.M.

HEAD OF THE DEPARTMENT OF PHYSICS
DETROIT CENTRAL HIGH SCHOOL

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W. P. I

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PREFACE

SINCE the first edition of this book was published the physical laboratory has become the rule rather than the exception in the schools. It is now possible to buy well made apparatus suitable for the laboratory of the secondary school at reasonable prices, so that at a cost of about one hundred dollars an equipment can be procured by which a good complete laboratory course can be established. Teachers also are more or less familiar with the general methods of laboratory procedure. For these reasons much of the matter in the former edition in regard to the size, form, and the making of apparatus has been omitted from this. In fact, the demands upon the time and energy of the science teacher are so heavy that it is believed he can spend his time to better advantage in other directions than in making apparatus. The school authorities should furnish the apparatus and a suitable place for storing it; the teacher should see that it is well taken care of, kept clean, and put away in good order as soon as he has finished using it.

Although laboratory work in our schools has been greatly extended in the last few years, the results have in many cases been disappointing. It has been said that the work is neither interesting nor instructive, and it is thought that the main cause of this is the severely quantitative character of the exercises. It may be that the quantitative aspect of the work has received too much emphasis and the qualitative too little. Every quantita-

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tive exercise, however, has its qualitative feature which the student should be brought to appreciate and understand, not through the quantitative work but as a preliminary to it. The author is of the opinion that the trouble has arisen not chiefly because the exercises are quantitative, but because of the nature of some of the experiments themselves and the character of the apparatus employed. Of what possible interest, for example, to the average girl, or boy for that matter, is an experiment in breaking wire? Or how is it possible to inspire respect for the subject and interest in it, when the apparatus and the methods used are such that the teacher must apologize for the results?

After twenty years of experience in the physical laboratory with large classes the author presents these exercises, which have been thoroughly tested in his own classes and in other schools, with a firm belief that a course can be selected from them which will be both instructive and interesting to the pupil. The methods and apparatus described will give good results in the hands of pupils.

The number of exercises is sufficiently large to allow considerable latitude of choice. The small school with a limited equipment or the large school with abundance of means can find suitable material for a laboratory course of one year. A few exercises are given which are suited for a little more advanced work which some may wish to give. The number of exercises also permits some variation of the work from year to year and gives room for development in the small school as its equipment increases.

If the teacher desires, the number of quantitative observations in many experiments may be reduced to a minimum and the qualitative feature of the work emphasized. Although the book contains several qualitative exercises, it is the author's firm conviction that the place for the purely illustrative experiment is in the lecture room rather than in the laboratory.

This manual is intended as a companion book for Adams's Physics for Secondary Schools, and the numbers in parentheses in the various exercises refer to paragraphs in that book. It may, however, be used separately, or with any other text.

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PHYSICAL LABORATORY MANUAL

CHAPTER I

SIMPLE MEASUREMENTS

EXERCISE 1

THE METER STICK

Purpose. — *To measure lengths by a meter stick, to estimate tenths of millimeters, and to learn how to record the results.*

Apparatus. — A meter stick. A sheet of paper and other objects which may be measured.

Procedure. — (1) Measure the length of a sheet of paper and several other objects less than a meter long to the nearest millimeter, expressing the results in centimeters and tenths of centimeters.

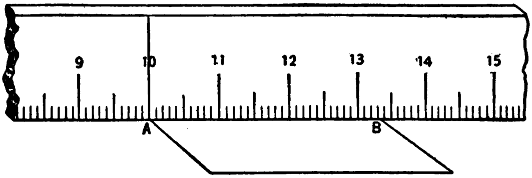


FIG. 1.

Place the meter stick on the object as in Figure 1, not as in Figure 2. Do not begin at the end of the meter stick, because the end may be worn or imperfect.

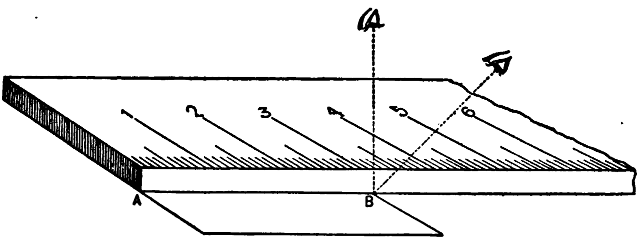


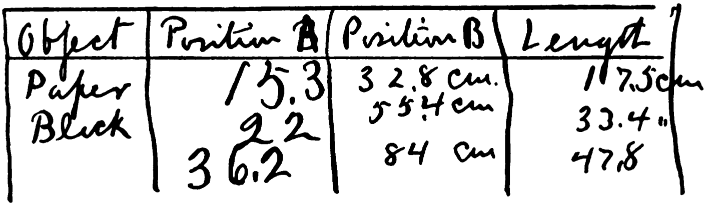
FIG. 2.

Do not count the centimeters from *A* to *B*, but note the position of *A* and the position of *B* on the measure and obtain the lengths by subtracting *A* from *B*.

Record your results in a way similar to this:

OBJECT	POSITION A	POSITION B	LENGTH
Paper	15.3 cm.	32.8 cm.	17.5 cm.
Block	22.0	55.4	33.4
Ruler	36.2	84.0	47.8

Possibly your record resembles the following in some particulars:



Object	Position A	Position B	Length
Paper	15.3	32.8 cm.	17.5cm
Block	22	55.4 cm	33.4"
	36.2	84 cm	47.8

The last record lacks the first element of a good record, that is, neatness. It is, moreover, incorrect in several respects. In the second column, the figures are too large; the denomination cm. is not given, and a proper space is not left for it; units are not placed under units, nor tens under tens. In the third column the cm. is written too many times. The faults of the last column are self-evident.

The numbers 22 and 84 should be written 22.0 and 84.0. "But," you say, "it came out exactly 22 and 84." Uniformity and neatness would suggest the addition of the decimal point and the cipher; but there is a better reason for their use. When you write it 22, the implication is that you are attempting to read only to the nearest centimeter and that you are not paying any attention whatever to the millimeters. 22.0 implies that you are reading to the nearest millimeter, which is the fact in the present case. The cipher, therefore, has a significance, and 22 does not mean, as you thought it did, that "it came out exactly 22"; it means that 22 was the nearest centimeter.

(2) Measure the same objects again, this time to the nearest tenth of a millimeter. It will be necessary to estimate the fractions of millimeters by the eye. Do not do it in halves or quarters, but in tenths. Of course, you cannot do it very accurately at first and there will be considerable uncertainty about these tenths.

A tenth of a millimeter is one hundredth of a centimeter. Express your results in centimeters and hundredths of centimeters, and see if you can avoid all the faults of your last record.

In some of your future experiments it will be possible and desirable to read to tenths of millimeters, in others only to tenths of centimeters, and possibly in some only to centimeters. See that your record always indicates what you are attempting to do.

EXERCISE 2

THE DIAGONAL SCALE

Purpose. — *To learn to use the diagonal scale.*

Apparatus. — A pair of dividers with sharp points. A diagonal scale (Fig. 3). A strip of brass with two small crosses ruled upon it.

Procedure. — (1) Determine the unit of the scale.

(2) Count the number of spaces into which the unit of the scale is divided by the diagonal lines at one end of the scale. Also count the number of spaces formed by the lines running lengthwise on the scale.

(3) Note that the diagonal lines and the horizontal lines form a large number of small parallelograms.

What is the length of the top and bottom of each of these parallelograms?

(4) Note that the first diagonal line, which starts at the zero of the scale, forms with the vertical from that point a triangle. How long is the base of this triangle?

(5) By geometry determine the length of all the lines in that triangle parallel to its base.

(6) How far is it, for example, on the fifth horizontal line from its intersection with the vertical from zero to its intersection with the second diagonal? on the third horizontal line? fourth? fifth? etc.

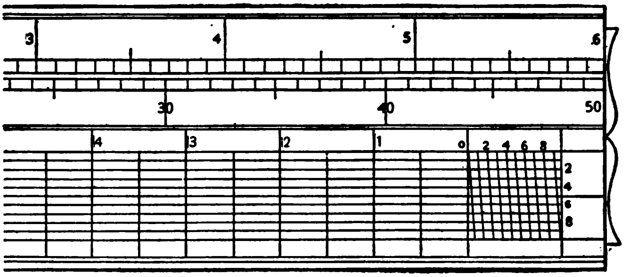


FIG. 3.

How far is it from the vertical on the fifth horizontal to the fourth diagonal? to the sixth diagonal? eighth? ninth?

(7) What do the diagonal lines represent or express? What the horizontal lines?

(8) By the aid of the scale, spread the points of the dividers so that they shall be 2.67 units apart; 3.08 units apart; 1.45; 2.11. Let the instructor verify in each case.

(9) By the dividers and the diagonal scale measure the distance between the points of intersection of the two crosses on the strip of brass. Let the instructor verify the measurement.

N.B.—Both points of the dividers must always be on the same horizontal line.

EXERCISE 3

THE VERNIER

Purpose. — *To learn to use the vernier, which is an auxiliary scale* (Fig. 4) *attached to a larger scale to enable one to read accurately very small parts of the divisions of the larger scale.* For example, if a scale is graduated in tenths of inches, it is possible by the aid of a vernier to read to hundredths of an inch by that scale.

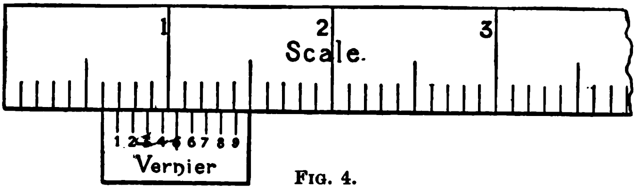


FIG. 4.

Apparatus. — A verniered caliper (Fig. 5) or other instrument having a scale with a vernier.

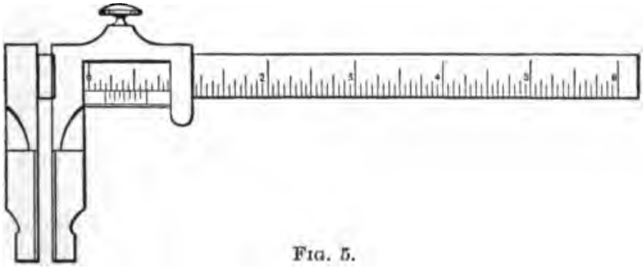


FIG. 5.

Procedure. — Before one can use a vernier he must determine its **least count**. It is found as follows:

(1) Determine the unit of the scale, whether it is an inch, centimeter, degree, or other unit.

(2) Count the number of divisions into which this unit is divided and calculate the value of the smallest division.

(3) Measure the length of the vernier by the large scale.

(4) Count the number of divisions into which the vernier is divided and calculate the value of its smallest division.

(5) Find the difference between the values obtained in operations 2 and 4. This difference is the least count. It is the smallest value that can be measured by this vernier and scale.

Record your results as follows:

Instrument			
Unit of the scale			
Length of scale division			
Length of vernier			
Length of vernier division			
Least count			

Having determined the least count of the vernier, let us learn how to use it.

The first line of the vernier is its zero line, and the others are numbered 1, 2, 3, etc.

First set the zero of the vernier on the zero of the scale; then move the vernier along the scale, say 5 units and 3 divisions of the unit, setting it so that its zero line exactly coincides with the line on the scale.

The zero of the vernier is now exactly 5 units and 3 divisions from the zero of the scale.

Move the vernier a tiny amount farther until its line 1 coincides with the next line beyond it on the scale. *How far did you move it?* What is the distance now between the zero of the scale and the zero of the vernier?

Again move the vernier a trifle more, so that its line 2 coincides with the next one beyond it. *How far did you move it?* What now is the distance between the two zeros?

Now move the vernier successively so that lines 3, 4, 5, etc., coincide with the next lines beyond them, and answer the above questions in each case.

If line 8 exactly coincides with a line of the scale, how far is the zero of the vernier from a line of the scale? line 6? line 4?

How can you tell into what parts the zero of the vernier divides a division of the scale?

EXERCISE 4

THE MICROMETER SCREW

Purpose. — *To learn to use the micrometer screw.*

Apparatus. — A micrometer screw (Fig. 6) is an instrument by which small dimensions are measured with great accuracy (§ 121).[1]

The screw *B* is threaded within the shaft *D* and is turned by the hollow cylinder *E*, which fits over the shaft *D*.

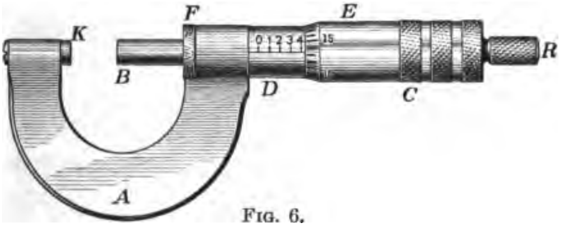


FIG. 6.

Turning the screw changes the distance between *B* and *K* and also moves the edge of the cylinder *E* an equal amount along the linear scale, on *D*. When *B* and *K* are in contact, the edge of *E* should be exactly on the zero of the linear scale and the zero of the circular scale should exactly coincide with the line running lengthwise on the cylinder *D* near the figures. When the screw is turned back, the distance between *B* and *K* is then exactly equal to the length of the linear scale exposed to view. The purpose of the circular scale is to enable one to read accurately the fraction of the last division of the linear scale exposed.

---

[1] Numbers in parentheses refer to sections in Adams's Physics for Secondary Schools.

Caution. — *Never use more than a very slight force in turning the screw. Hold C lightly, so that the fingers will slip if the screw turns hard; or if there is a ratchet, R, always turn the screw up by that.*

Procedure. — (1) Determine the unit, and also the value of the smallest division of the linear scale. If this cannot be done by inspection, turn the screw back until a considerable portion of the scale is visible, and then by a pair of dividers compare twenty, or more, divisions of it with both English and metric standard rules.

(2) Determine the pitch (§ 119) of the screw. This is done by observing how far the edge of *E* moves along the linear scale when the screw is turned around exactly once.

(3) Ascertain the number of divisions in the circular scale and calculate the **least count** of the instrument; this is the distance measured on the linear scale when the screw turns one circular division. For example, if the pitch of the screw is 0.5 mm. and there are 50 divisions on the circular scale, then the screw moves lengthwise 0.5 mm. when turned all the way around, but only $\frac{1}{50}$ of 0.5 mm., or 0.01 mm., when turned one circular division. Five circular divisions then mean 0.05 mm.; 10 circular divisions, 0.10 mm.; etc.

(4) Set the screw at different positions and read the

distances indicated, asking the instructor to verify your readings. The distance between *B* and *K* is obtained by adding the fraction of a division indicated by the circular scale to the number of whole divisions exposed to view.

An object is measured by placing it between *B* and *K* and turning the screw up until contact occurs, or until the object is just held by the screw, *the caution given above being observed.*

Record data as follows:

Instrument	
Unit of linear scale	
Size of smallest division of linear scale	
Pitch of screw	
No. of divisions on circular scale	
Least count	

EXERCISE 5

THE BEAM BALANCE

Purpose. — *To weigh an object by a beam balance.*

Apparatus. — A beam balance (Fig. 7) and a box of weights. Fine chemical balances are inclosed in glass cases to exclude the dust and to protect the balance from currents of air. When not in use, the beam is raised from the knife edges; and there are rests under the pans to steady them. The beam is lowered for use by turning a milled head or a lever in front of the instrument, and the rests underneath the pans are lowered by pushing in a small stop or pin. A long, slender pointer is attached to the beam, and swings to and fro over a scale as the beam vibrates.

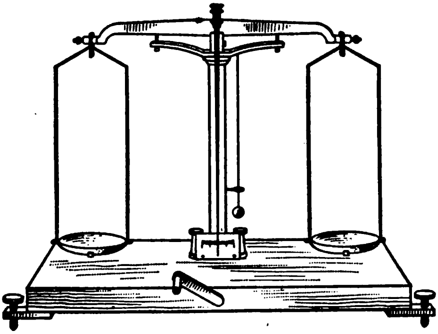


FIG. 7.

Procedure. — (1) Before the balance is used each day, it should be leveled; this is done by a spirit level or a small plumb bob attached to the balance.

(2) The **position of rest** for the pointer after it ceases swinging should be determined. This does not often coincide exactly with the middle point of the scale, and it is not well to try to adjust it so that it will, if it is near it. It requires too much time to wait for the beam to cease swinging in order to determine the position at which the pointer would come to rest; and hence the position of rest is found by observing the turning points of the pointer, while it is vibrating, and taking the mean of these points. The position of rest, however, is not midway between any two consecutive turning points, since friction and the resistance of the air reduce the amplitude of vibration at each swing; but it is found by taking an odd number of turning points, say 3 to the left and 2 to the right. This will throw the greatest and the least on the

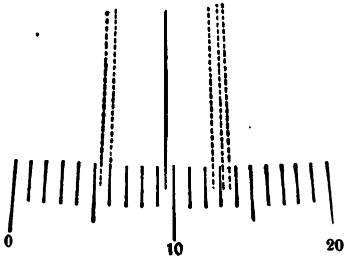


FIG. 8.

same side. For example, suppose the pointer to move over a scale having twenty divisions, and imagine these divisions to be numbered (Fig. 8) from 0 on the left to 20 on the right (not from the center in both directions). Suppose the following observations are taken:

TURNING POINTS

	Right	*Left*
	13.6	
		5.4
	13.2	
		6.0
	12.5	
	3)39.3	2)11.4
Mean	13.1	5.7

$$\frac{13.1 + 5.7}{2} = 9.4,$$ position of rest.

In weighing a body, the weights are adjusted until the pointer has the same position of rest as at first; this position is found as before, not by waiting for the beam to cease swinging. In observing the pointer, the operator should be directly in front of the center of the scale so that the line of sight is normal to the scale.

No person is fitted to use a sensitive balance unless he is able and willing to conform to the following rules:

Rules for Weighing. — (1) *See that the balance is level, and that the pans are free from dust. Use a camel's-hair brush for removing the dust.*

(2) *Sometimes the beam of the balance will not start to vibrate of itself. To set it swinging, waft a little air upon it by a quick movement of the hand, or touch it very lightly by the tip of the camel's-hair brush.*

(3) **See that all of the weights are present in the box before beginning to weigh, and place the box conveniently near the right-hand pan.**

(4) *Never place objects or weights on the pans, nor remove them from the pans except when the beam is raised from the knife edges and the balance is at rest.*

(5) *In arresting the beam, always wait until the pointer is over the center of the scale. The beam should always be raised slowly and carefully to avoid injuring the knife edges.*

(6) *Never touch the weights with the fingers, but lift them with forceps provided for the purpose.*

(7) **The weights should never be anywhere but on the pan or in their places in the box.**

(8) **Place the object to be weighed in the left-hand pan and the weights in the right-hand pan of the balance.**

(9) **Do not select weights to place upon the pan in a haphazard way, but take first the largest one you can use and then add others in their order from the largest to the smallest. Should you fail to follow this rule, you may place a large number of small weights upon the pan only to find that you must remove them all and substitute a larger weight for them which you failed to try.**

(10) **Check the final result that has been found by adding the weights on the pan, by noting the vacant places in the box, and adding the weights belonging therein.**

(11) *The object to be weighed should be cool, and nothing that is wet or that would injure the pan must be placed directly upon it.*

(12) *Final observations must be taken with the balance case closed to avoid currents of air.*

The rules printed in heavy type apply as well to larger and coarser balances and should always be observed.

EXERCISE 6

THE JOLLY BALANCE

Purpose. — *To study the action of the Jolly balance and to learn to weigh objects by it.*

Apparatus. — A Jolly balance (Fig. 9). A set of metric weights. The long, slender spiral spring of the balance has near its lower end a bead or pointer which is used as an index in measuring the change in length of the spring. If you sight past this index at the scale back of it, you will notice that the position of the index on the scale changes when the eye is raised or lowered. This apparent displacement of the index due to different positions of the eye is called **parallax**. In observing the position of the index on the scale, parallax must be avoided. It is done by using a mirror scale and always placing the eye so that the index covers its own image in the mirror.

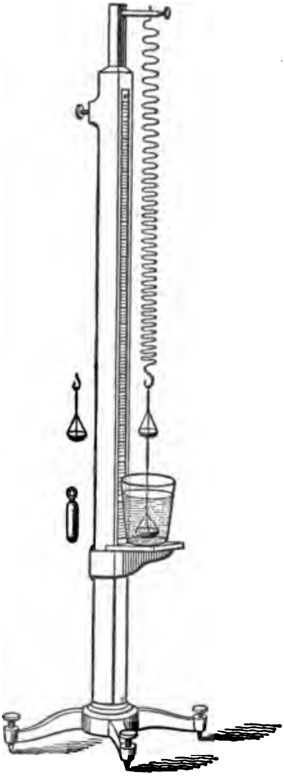


FIG. 9.

Procedure. — (1) Read and record the position of the index of the spring with no load in the pan.

(2) Place a 2 g. weight in the pan and take the position of the index again. Find the elongation of the spring by taking the difference between the average reading without load and the reading with load.

(3) Repeat with 4, 6, 8, 10 g., etc., always taking the position of the index both before and after using each weight. Your instructor will tell you the largest weight you may use.

Record your results as follows:

BALANCE NO. 5 SPRING 2 MODULUS .548

READING WITHOUT LOAD	AVERAGE WITHOUT LOAD	READING WITH LOAD	LOAD OR STRESS	ELONGATION OR STRAIN	LOAD ÷ ELONGATION
5.10 cm.	5.13 cm.	8.80 cm.	2.00 g.	3.67 cm.	.545
5.15	5.15	12.50	4.00	7.35	.544
5.15	5.18	16.15	6.00	10.97	.547
5.20	5.20	19.68	8.00	14.48	.552
5.20	5.20	23.40	10.00	18.20	.547
5.20	5.20	27.10	12.00	21.90	.548
5.20	5.23	30.75	14.00	25.52	.549
5.25	5.23	34.45	16.00	29.22	.548
5.20	5.23	38.10	18.00	32.87	.548
5.25	5.23	41.65	20.00	36.42	.549
5.20					

Discussion. — Having obtained the data, we should now study the table to see what the results teach. Examine the results in the fourth and fifth columns. How do different loads affect the elongation? Is the elongation doubled when the load is doubled? Is the elongation tripled when the load is multiplied by 3? If so, probably the elongations are proportional to the loads. To test this, you might take any two of the loads and their corresponding elongations and form a proportion with them, and then prove the proportion to see if it is true; but if you have used 10 different loads in your experiment, there are 45 different proportions which you might form and prove before you would exhaust the problem. This would be a tedious way to find out whether the elongations are always proportional to the loads. There are much better methods.

In the last column you have the ratio of the load to the elongation. Is this ratio for the first trial equal to that for the second trial? If so, these loads and elongations are proportional, for a proportion is by definition an equality of ratios. Are all these ratios the same or constant only sure figures being considered? If so, all of the elongations are proportional to the loads. It is a law of mathematics that *when the quotients of two variable quantities are constant, the two quantities are directly proportional.* The last column tells at a glance whether the loads and elongations are proportional or not.

Find the average of the last column. This is the number of grams required to elongate the spring 1 cm., and is called the **modulus** of the spring. Since the modulus is the number of grams causing an elongation of 1 cm., it will require 2 times as many grams to elongate it 2 cm., or 7.6 times as many grams to elongate it 7.6 cm., etc. Hence, the weight of any body is obtained by multiplying the elongation it produces by the modulus of the spring.

This experiment illustrates Hooke's Law (§ 143).

EXERCISE 7

GRAPHIC REPRESENTATION OF RESULTS

Purpose. — *To learn to plot a curve and to show graphically the relation between two related quantities, such, for example, as the load and elongation of a Jolly balance spring.*

Apparatus. — A sheet of coördinate paper. Such paper (Fig. 10) is ruled in small squares, preferably in centimeters and millimeters, or in inches and tenths of inches, every fifth and tenth line being heavier than the others.

Some point on the paper, usually the lower left-hand corner, is called the **origin** and is always marked *O*. The

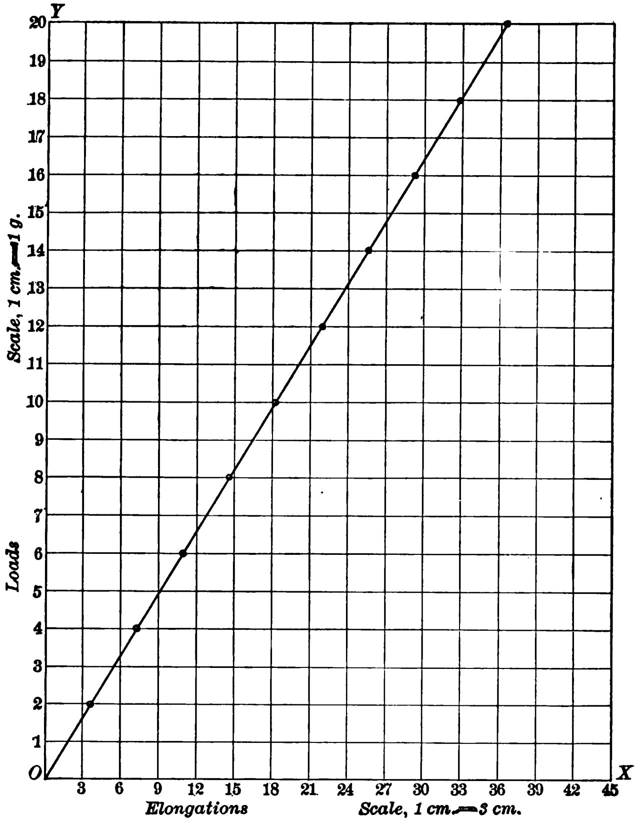


FIG. 10.

horizontal line through the origin is the **axis of abscissas,** or simply the axis of *X*, being always marked *X*; and the vertical line through *O* is the **axis of ordinates,** or the axis of *Y*, being always marked *Y* at the upper extremity. Quantities represented on *X* are called **abscissas**, and those on *Y* **ordinates.**

Let us illustrate the method of procedure by the data of the last exercise. This work should be regarded as a drawing rather than as a written exercise, and should be executed with all the neatness and exactness possible.

Procedure. — (1) Choose a point for the origin and mark it *O*, and mark the axes of *X* and *Y* by the letters *X* and *Y* (Fig. 10).

(2) Decide which quantity you will represent on the axis of *X*, loads or elongations; you may choose either. Suppose you let elongations be the abscissas. Print in neat characters the word "elongations" near that axis.

(3) Choose a suitable scale by which the different values are to be laid off on the axis. Print the scale chosen, and mark how much each heavy line represents, as shown in the figure.

In doing this you will need to use your own judgment as to what scale is best and most convenient. Do not make it so small that only a small portion of the sheet is occupied by the completed work, nor so large that the paper will not be large enough for the work. By dividing the largest number to be represented by the number of squares, we can see what scale may be used. $36.42 \div 15 = 2.4+$. Hence, 1 cm. may be used to represent 2.4 or any larger number of centimeters of elongation. We should not let 1 cm. represent a smaller number, for the sheet would not be large enough for the curve; neither should we let it represent a much larger number, for if we did, the curve would occupy too little space on the paper. We might choose 2.5, but 3 will be easier to work out.

(4) Since the elongations are abscissas, the loads will be the ordinates. Print the word "loads" along the axis of *Y* and choose a suitable scale to represent the loads. In this case there are 20 squares and 20 g. is the largest load.

It is easy to see that 1 cm. should represent 1 g. Mark each heavy line with the number of grams it represents.

(5) Find a single point on the paper that will represent both the first load and its corresponding elongation. The load and its elongation are the **coördinates** of this point.

Any point on the horizontal line 2 cm. from *OX* will represent the load of 2 g. Since 1 cm. = 3 cm. of elongation, 1.22 cm. (3.67 ÷ 3 = 1.22) will represent 3.67 cm. of elongation. Hence, any point on a vertical line 1.22 cm. from *OY* will represent the elongation. The desired point is at the intersection of these two lines.

Use a sharp-pointed pen and mark this point with a dot and small circle, ⊙, or with a small oblique cross, x.

In like manner locate and mark points for all other coördinates.

(6) Draw a fine smooth line that will hit as many as possible of these points. This line is called a curve whether it is curved or straight. Do not draw a broken or wavy line from point to point.

Discussion. — Curves drawn in this way are extremely useful in science. They often tell at a glance the relation between two quantities, even when the exact mathematical relation is unknown.

When the curve is a straight line, as in this case, it shows that the two quantities are directly proportional; a fact we had previously learned in a different way.

If a point falls without the curve, it is probable that an error or mistake was made in obtaining the data for that point. Thus the curve may serve to detect errors in the work and mistakes in the calculations. Such a curve is often useful for determining intermediate values for one of the quantities corresponding to given values of the other quantity. For example, we can see that a body which causes an elongation of 30 cm. weighs about 16.4 g., and the weight of a body causing an elongation of 18 cm. weighs 9.8 g. What would be the weight of a body causing an elongation of 34.5 cm.? Determine it by the curve; also by the method given in the last exercise, and compare the two results.

EXERCISE 8

DENSITY OF A RECTANGULAR PRISM

Purpose. — *To determine the density of . . . . wood from a rectangular prism of that substance.*

Apparatus. — A Jolly balance or a beam balance. Steel rules, verniered calipers, or dividers and diagonal scale. A small rectangular prism of wood.

Procedure. — (1) Measure the length, breadth, and thickness of the block several times, each time in a different place.

(2) Weigh the block by the Jolly balance or by a beam balance. (Use the curve you have drawn.)

(3) From the average of the measurements taken, find the volume of the block, and calculate the mass of 1 c.c. (cubic centimeters) of the substance composing the block. This will be the **density** of that substance. What is density? (§ 15.)

(4) Repeat the above, using English instead of metric units, and finding the mass (expressed in ounces) of 1 cu. in.

If means are not at hand for finding the weight in ounces, reduce the weight in grams to ounces. (See Table 1, Appendix.)

As a test of the accuracy of your work, reduce the volume in cubic centimeters obtained by measurement to cubic inches, and the volume in cubic inches to cubic centimeters.

Tabulate the data as follows:

Object _____________*						
	Metric Units			English Units		
	Length	Breadth	Thickness	Length	Breadth	Thickness
1						
2						
3						
4						
5						
Average						
Volume						
Reduced volume						
Weight						
Density of ___________*						

* State the kind of wood or the name of the substance.

SIGNIFICANT AND DOUBTFUL FIGURES

The number of figures to be kept in a result often troubles a student. He usually retains altogether too many in multiplying and too few when dividing. "How many decimal places shall I keep?" he asks, when in fact it is not a question of decimal places at all, and he should never ask that question. He should ask, "How many significant figures shall I keep?" In some cases he may keep three, in others only two, possibly in others four; it depends upon the accuracy with which the measurements entering into the problem can be taken. If he should keep three figures, he may not have any decimal places, or he may have six, or more or less, as the case may be. The rules of arithmetic, if followed, will take care of the decimal point; other considerations will decide the number of significant figures to be kept. The student should remember that no measurement can be made which is known to be exactly right. *Errors* always occur in every measurement.

The best usage is to retain one doubtful figure only. However, in the average of a number of observations, one more figure may be retained than in the individual observations, especially if the difference between the several observations is small. Figures following a doubtful one are not merely doubtful, they have no significance whatever.

How shall one decide what figures are sure and what are doubtful? In results obtained directly from *observation* the student must use his judgment in deciding how many figures are sure. If, for example, the last figure is obtained by estimating the fraction of a division, it is of course doubtful; and if in measuring the same thing several times the results vary, the figures that differ are in doubt.

In results obtained by *calculations* based upon the results obtained from experiment, the student can see what figures are doubtful by underlining or writing in red ink all doubtful figures throughout the process, but rules III and IV render this process unnecessary.

The following rules should be observed in recording results:

I. *Reject all figures after the first doubtful figure. If necessary, substitute ciphers for the rejected figures to locate the decimal point.*

II. *Increase the last figure retained by* 1, *if the rejected figure following it is* 5 *or greater than* 5.

III. *Retain in products no more figures than there are in the factor having the least number of sure figures. This rule is* *not invariable. It is better to retain two doubtful figures throughout the calculations until the end, when the rule may be applied.*

IV. *Retain in quotients as many figures as there are in the factor having the fewest number of sure figures. Carry the division to one more figure than you intend to keep so that you can observe Rule II.*

V. *Ciphers added or prefixed merely for the purpose of locating the decimal point do not count as significant figures; others do count.*

Let us illustrate these rules and principles by the following data taken from a student's notebook:

Object — *Maple block*						
Metric Units				English Units		
Trials	Length	Breadth	Thickness	Length	Breadth	Thickness
1	$3.2\underline{2}$ cm.	$2.8\underline{7}$ cm.	$1.8\underline{7}$ cm.	$1.2\underline{5}$ in.	$1.1\underline{3}$ in.	$.7\underline{5}$ in.
2	$3.2\underline{4}$	$2.8\underline{5}$	$1.8\underline{7}$	$1.2\underline{5}$	$1.1\underline{4}$	$.7\underline{6}$
3	$3.2\underline{5}$	$2.8\underline{5}$	$1.8\underline{6}$	$1.2\underline{6}$	$1.1\underline{3}$	$.7\underline{4}$
4	$3.2\underline{5}$	$2.8\underline{6}$	$1.8\underline{7}$	$1.2\underline{7}$	$1.1\underline{2}$	$.7\underline{3}$
5	$3.2\underline{4}$	$2.8\underline{7}$	$1.8\underline{8}$	$1.2\underline{7}$	$1.1\underline{3}$	$.7\underline{2}$
Average	$3.2\underline{4}$	$2.8\underline{6}$	$1.8\underline{7}$	$1.2\underline{6}$	$1.1\underline{3}$	$.7\underline{4}$
Volume $17.\underline{328168}$ c.c.				$1.0\underline{53612}$ cu. in.		
Reduced volume $17.\underline{265539844}$ cc.				$1.0\underline{5736481136}$ cu. in.		
Weight $12.\underline{2}$ g.				$0.43\underline{03428}$ oz.		
Density of Maple = .7 g. per c.c.				0.4 oz. per cu. in.		

Observe how inconsistent this pupil was in retaining from seven to twelve figures to express the volumes, while he used only one in the final result.

The doubtful figures are underlined. The volumes of the block were obtained as follows:

(*a*)

$$\begin{array}{r} 3.2\underline{4} \\ 2.8\underline{6} \\ \hline 1\underline{9}\underline{4}\underline{4} \\ 259\underline{2} \\ 64\underline{8} \\ \hline 9.2\underline{6}\underline{6}\underline{4} \\ 1.8\underline{7} \\ \hline \underline{6}\underline{4}\underline{8}\underline{6}\underline{4}\underline{8} \\ 741\underline{3}\underline{1}\underline{2} \\ 92\underline{6}\underline{6}\underline{4} \\ \hline 17.\underline{3}\underline{2}\underline{8}\underline{1}\underline{6}\underline{8} \end{array}$$

(*b*)

$$\begin{array}{r} 9.2\underline{7} \\ 1.8\underline{7} \\ \hline \underline{6}\underline{4}\underline{8}\underline{9} \\ 741\underline{6} \\ 92\underline{7} \\ \hline 17.\underline{3}\underline{3}\underline{4}\underline{9} \end{array}$$

(*c*)

$$\begin{array}{r} 1.2\underline{6} \\ 1.1\underline{3} \\ \hline \underline{3}\underline{7}\underline{8} \\ 12\underline{6} \\ 12\underline{6} \\ \hline 1.4\underline{2}\underline{3}\underline{8} \\ .7\underline{4} \\ \hline \underline{5}\underline{6}\underline{9}\underline{5}\underline{2} \\ 99\underline{6}\underline{6}\underline{6} \\ \hline 1.0\underline{5}\underline{3}\underline{6}\underline{1}\underline{2} \end{array}$$

(*d*)

$$\begin{array}{r} 1.4\underline{2} \\ .7\underline{4} \\ \hline \underline{5}\underline{6}\underline{8} \\ 99\underline{4} \\ \hline 1.0\underline{5}\underline{0}\underline{8} \end{array}$$

Compare the reduced volumes in the table which were obtained by using all the doubtful figures with results obtained as follows:

(*e*)

$$\begin{array}{r} 17.\underline{3} \\ .06\underline{1}\ (.06102) \\ \hline 173 \\ 1038 \\ \hline 1.0\underline{5}\underline{5}\underline{3} = 1.06\text{ cu. in} \end{array}$$

(*f*)

$$\begin{array}{r} 1.0\underline{5}\underline{4} \\ 16.\underline{4}\ (16.387) \\ \hline \underline{4}\underline{2}\underline{1}\underline{6} \\ 63\underline{2}\underline{4} \\ 105\underline{4} \\ \hline 17.\underline{2}\underline{8}\underline{5}\underline{6} = 17.\underline{3}\text{ c.c.} \end{array}$$

It is wrong to retain so many doubtful figures as in (*a*) and (*c*). First, it involves useless labor. Notice in (*b*), (*d*), (*e*), and (*f*) how much labor is saved by applying rules I and II to the problem. Also note that the results are just as accurate because all of the sure figures and even the first doubtful figures agree. Second, such a record is a mere pretense to an accuracy not possible under the given conditions; hence, it is untruthful and misleading. All figures after the first doubtful one are worthless and meaningless.

If the above rules are applied to the calculations, the results will be expressed in three figures as follows:

Volume,	17.3 c.c. or 1.05 cu. in.
Reduced volume,	17.3 c.c. or 1.06 cu. in.
Weight,	12.2 g. or 0.430 oz.
Density of Maple,	0.705 g. per c.c. or 0.402 oz. per cu. in.

Let the pupil revise his records in Exercises 6 and 8, underlining or writing in red ink all doubtful figures in observations and calculations and apply the rules to the work.

EXERCISE 9

DENSITY OF A CYLINDER

Purpose. — *To determine the density of . . . . from a cylinder of that metal* (§§ 14, 15).

Apparatus. — A small cylinder of brass or other metal. Calipers, steel rules, or dividers and diagonal scale. Two square-cut blocks (Fig. 11) and a meter stick.

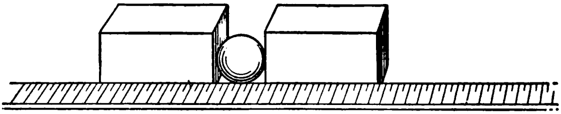


FIG. 11.

Procedure. — (1) Find the average dimensions of the cylinder, being careful to measure its diameter at several different places and in different directions.

The diameter may be measured either by calipers or by placing the cylinder between two square-cut blocks whose sides are placed against a ruler and then measuring the distance between the blocks. Do not begin at the end of a rule to measure, but measure between two marks on the scale, estimating tenths of a millimeter by the eye. The distance between the blocks can also be measured by the use of the dividers and the diagonal scale.

(2) Weigh the cylinder and determine its density as in the preceding exercise. (See Table 2, Appendix, for formula for calculating the volume of the cylinder.)

Use a tabular form similar to that on page 30, making two instead of three columns for the dimensions.

EXERCISE 10

DENSITY OF A SPHERE

Purpose. — *To determine the density of . . . . from a sphere of that substance.*

Apparatus. — Same as for Exercise 9. A small sphere of wood or metal. The verniered caliper or the micrometer screw may be used for making the measurements.

Procedure. — (1) Measure the diameter of the sphere in several different directions. If the blocks (Fig. 11) are used, estimate by the eye the tenths of a millimeter.

(2) Weigh the sphere and determine its density as before. (See Table 2, Appendix, for formula for calculating the volume of a sphere.)

Use a tabular form similar to that given for Exercise 8, having only one column for the dimensions.

CHAPTER II

MECHANICS OF SOLIDS

EXERCISE 11

UNIFORMLY ACCELERATED MOTION

Purpose.—(1) *To determine the resultant of uniform and uniformly accelerated motion, the two motions being at right angles to each other* (§ 60).

(2) *From a study of the curve thus generated to derive the laws of uniformly accelerated motion* (§ 30).

Apparatus.—A Packard Machine (Fig. 12). This machine consists of an inclined plane made of a glass plate. An auxiliary inclined plane *A* gives a steel ball, one inch in diameter, uniform motion across the plate while it rolls down the plane with uniformly accelerated motion. The ball is made to trace its path on coördinate

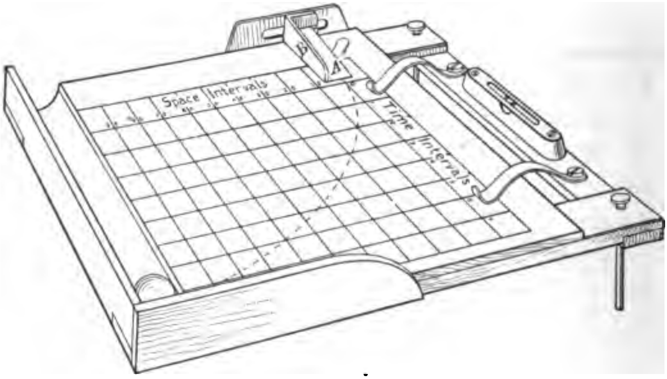


FIG. 12.

paper by rolling upon carbon paper. Soft carbon transfer paper and coördinate paper marked with time intervals across the top and space intervals at the left are used. The plane should be inclined until the ball will not roll off the paper at the right before it reaches the bottom.

Procedure.—(1) See that the upper edge of the plane is level. (In reality the left-hand corner should be just a trifle higher than the right or the motion across the plane will not be quite uniform but slightly retarded by friction, thus making the time intervals toward the last longer than at first.)

(2) Turn the clip aside and place a sheet of coördinate paper on the plane as shown in Figure 12. Be sure that it is in contact with the guide at the bottom and that the vertical zero line is exactly at the end of the ledge *B*. Turn the clip back again to hold the paper in place.

(3) Loosen the screw and adjust the auxiliary plane so that a mark on it is exactly on the horizontal zero line of the paper, or so that the ledge is exactly one half inch below this zero line. If the auxiliary plane is properly placed, the ball on rolling off of it will strike the paper exactly on the zero line.

(4) Place a sheet of carbon paper, sensitive side down, over the coördinate paper and test the adjustment of the auxiliary plane, by allowing the ball to roll as far as the end of the ledge only. Lift the carbon paper to see if it strikes exactly on the zero line. If not, readjust the auxiliary plane and replace the carbon paper.

(5) When all is ready, place the ball at the left-hand end of the auxiliary plane and allow it to roll down the plane.

Discussion.—Remove the paper from the machine and make a careful study of it. Since the ball moves toward the right with uniform motion, the heavy vertical lines mark off equal intervals of time t. The intersections of the line made by the ball with these vertical lines tell where the ball was at the end of each equal interval of time.

Count the number of small squares from the top line to each of these intersections, estimating the tenths. This will give you the spaces traversed with uniformly accelerated motion in 1, 2, 3, etc., intervals of time.

Record the results as follows:

t	s	AVERAGE VELOCITY, V_a	FINAL VELOCITY, v	ACCELERATION, a	$s = \frac{1}{2}at^2$

Find the average velocity (§ 21) for 1 unit, 2 units, etc., of time by dividing s by t.

Find the final velocity or velocity at the end of each interval of time by multiplying the average velocity by 2; because when a body has uniformly accelerated motion, its average velocity or $V_a = \frac{0+v}{2}$. Clearing of fractions, we have $2\,V_a = v$ (§ 30).

Find the acceleration by dividing the final velocity v for the end of any given unit of time by the time t (§§ 28 and 30).

Find the average of the results obtained for a and with this average compute s for the different time intervals by the formula $s = \frac{1}{2}at^2$ and place the results in the last column. Compare these results with those of the second column.

EXERCISE 12

COMPOSITION OF CONCURRING FORCES

Purpose. — *To study the composition of two concurring forces and to find their resultant and equilibrant* (§§ 50, 51).

Apparatus. — Three spring balances. Two pieces of fish line. A block of wood about a foot long having a nail or hook projecting from it near one end. A clamp.

Procedure. — (1) Connect the hooks (Fig. 13) of two of the balances by a cord 50 to 60 cm. long, having first passed it through a loop in the end of another cord 20 to 30 cm. long. Attach this shorter string to the hook of the third balance.

(2) Place the balances thus connected backs down on the table, passing the rings of the first two over nails driven in the table 30 to 50 cm. apart.

If the indexes of the balances are not at zero when in this position, allowance must be made for their displacement in all future readings.

(3) Now pull the third balance toward the opposite side of the table until each balance registers several units, but see that none of them is stretched to its full extent. Fasten this third balance in place by attaching it to the hook in the block of wood and clamping this block to the edge of the table.

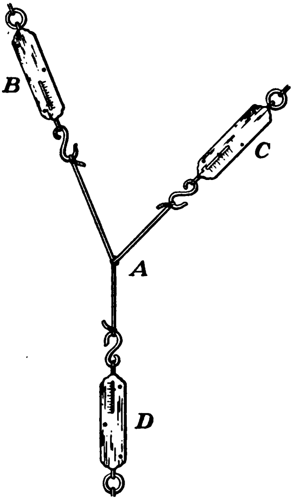


FIG. 13.

(4) Place the notebook or a sheet of paper under the junction of the cords, and place two dots 10 or 15 cm. apart exactly under each cord. Through these dots draw lines to the point of intersection. If the three lines do not meet at a common point, repeat the experiment. Success in this experiment depends largely upon the accuracy and care with which these lines are drawn. Secure the

notebook by weights or the paper by pins, and use a pencil with a fine point, and a thin-edged ruler.

(5) Read each balance with great care, and record the force denoted by it upon the line running toward the balance from which the reading is taken.

In writing the remainder of the exercise, the student should observe strictly the order indicated in the following notes and questions:

(6) Designate the junction of the lines by *A* and the direction of the forces by arrowheads.

(7) Lay off from *A* distances to represent the magnitudes of the forces recorded on the lines, indicating them by *B*, *C*, and *D*.

(8) Extend any one of the lines from *A* an equal distance in the opposite direction, and designate it by *E*. Connect the point *E* with the extremities of the distances laid off on the two adjacent lines.

(9) What is the force opposite to *AE* called with reference to the other two forces? Why? (§ 53.)

(10) What is the force *AE* called with reference to its two adjacent forces? Why? (§ 54.)

(11) What figure has been formed, and what part of that figure is *AE*?

EXERCISE 13

PARALLEL FORCES

Purpose. — *To study the composition of two parallel forces.*

Apparatus. — Two 250-g. spring balances graduated in 10-g. spaces. A light wooden bar a meter long, graduated in millimeters and having wire loops at each end for the insertion of the hooks of the balances. A horizontal rod upon which the balances may be supported (Fig. 14). A set of weights.

Procedure.—(1) Arrange the apparatus, draw a diagram of it, and letter it as in Figure 14.

(2) Remove the weight *F* and note and record the positions of the indexes of the two balances. Subtract these readings from all subsequent readings.

(3) Suspend a 200-g. weight *F* on the bar by a thread at the center of the bar, that is, at the 50 cm. mark. Record the lengths *CE* and *DE* and the forces registered on *A* and *B*, remembering to subtract the readings obtained under paragraph 2. Repeat this operation, placing the weight *F* at 40 cm., 30 cm., etc., from one end of the bar.

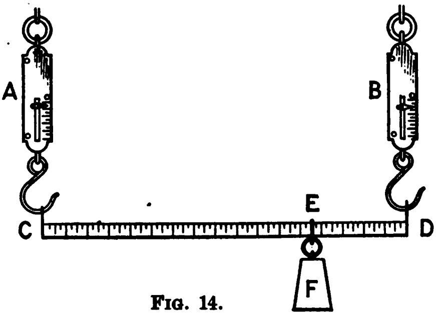


FIG. 14.

FORCE AT *F*	FORCE AT *A*	FORCE AT *B*	LENGTH *CE*	LENGTH *DE*	$A+B$	$A \times CE$	$B \times DE$

Discussion. — What is the force *F* with reference to the forces *A* and *B*? Tell why (§ 54).

What is a force equal and opposite to *F* with reference to the forces *A* and *B* called? Tell why (§ 55).

Can you form a proportion from $A \times CE$ and $B \times DE$? If so, make *A* and *CE* the extremes and *B* and *DE* the means of the proportion and state the significance of the proportion.

Remember in drawing inferences that if the balances are graduated in 10-g. spaces, the grams in unit places are estimated and hence are doubtful.

EXERCISE 14

THE PENDULUM

Purpose. — *To show the relation between the length of a pendulum and its time* (§§ 76–81).

Apparatus. — Some fine thread. A large bullet. A stop watch or a clock with a sweep-second hand. The clock should have an electric attachment and be connected with a telegraph sounder so as to sound every second. Calipers. A clamp (Fig. 15) with square jaws. A rod (Fig. 16) for measuring lengths of pendulums.

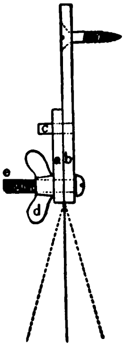


FIG. 15.

Caution. — Do not allow the arc of swing to be greater than about $\frac{1}{10}$ of the length of the pendulum.

Procedure. — (1) Measure the diameter of the bullet.

(2) Tie a piece of thread about 2 m. long to the bullet and suspend the bullet from the clamp as shown in Figure 15, making the pendulum from 150 cm. to 200 cm. long.

(3) Measure the length of the pendulum. To do this hold the end of the rod *A* against the lower edge of the clamp, then slide the bar *B* up until it just touches the lower surface of the bullet. Fasten the bar by the set screw. Place the rod on a table and measure by two meter sticks the distances from the end of the rod to the bar. Subtract from this length the radius of the bullet. This gives the length of the pendulum because the center of the bullet may be called the center of oscillation of the pendulum.

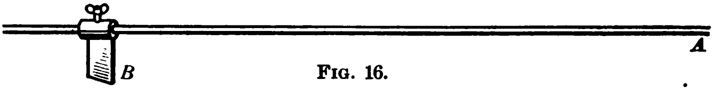


FIG. 16.

(4) Determine the time of the pendulum, that is, the time required to make one swing. This is done by finding the time required for a large number of swings or vibrations and dividing this time by the number of swings.

Method of Taking the Time. — First learn to express time properly. For example, instead of recording a time as 15 min. and 12 sec. of 10 o'clock, write it 9 hr. 44 min. 48 sec. Let the whole class practice until all can record correctly the time at which the instructor taps the table with a pencil.

There should be a heavy vertical line just back of the pendulum at rest. When it is swinging, the passage of the pendulum thread past this mark is called a **coincidence.** A coincidence between this pendulum and the clock pendulum also occurs, when the tick of the latter occurs at the same time as the former passes the line.

Let one person (*A*) count the swings of the pendulum while another (*B*) records the times of beginning and ending the count. Before starting let them agree on about how many vibrations will be counted, say about 50 or about 100. The count should begin and end with a coincidence between this pendulum and the clock pendulum.

Let *A* watch the pendulum and when a coincidence occurs, give a signal to *B* by tapping the floor with a ruler, at the same time beginning the count with the word "zero" and counting 1, 2, 3, etc., at each succeeding passage of the pendulum by the mark.

Let *B* watch the clock, and when he hears the signal from *A*, note the exact second and minute and record the time of beginning.

When the count approaches 50 or 100 vibrations, let *A* give a warning signal to *B* so that the latter shall be watching the clock. When *A* is ready to end his count, let him do it at a coincidence with the clock pendulum, tapping the floor at the time so that *B* can note and record the time of ending. *A* can close the count at any coincidence he pleases (not exactly at the 50th or 100th), provided *B* is ready to hear his signal and note the time.

At the next trial *A* and *B* should exchange work. It is probable that your first results will not be at all accurate. Continue the work until you get at least three results that agree fairly well; then take a shorter pendulum and repeat the work. If time permits, take another length.

If a stop watch is used, the work is much simpler. Start the watch at a coincidence, at the same time starting the count with the word "zero." After counting about 50 or 100 vibrations stop the watch at a coincidence, remembering the count at which you stop.

Record the results as follows:

RADIUS OF BULLET............							
LENGTH OF PENDULUM	TIME OF BEGINNING	TIME OF ENDING	WHOLE TIME	NO. OF VIBRATIONS	TIME, t, OF ONE VIBRATION	SQUARE ROOT OF LENGTH $\sqrt{l}$	$\frac{t}{\sqrt{l}}$

Discussion. — In the sixth column draw a line under the results obtained for any given length and place the average of the results below it.

If the results in the last column are constant (as far as the sure figures) for all lengths, then you have derived a proportion. State this proportion in words.

Call this constant in the last column *K*. The time of a pendulum of any length divided by the square root of its length should equal *K* in your locality, or $\frac{t}{\sqrt{l}} = K$: If you know t and K, you can find l. From your value for K calculate l when $t=1$, and thus find the length of a second's pendulum for your locality.

From the value of l for a second's pendulum just obtained and the formula $t=\pi\sqrt{\frac{l}{g}}$ calculate the value of g for your locality.

EXERCISE 15

THE PENDULUM. LENGTH OF ARC

Purpose. — *To show the effect of amplitude on the time of vibration of a pendulum* (§ 81).

Apparatus. — Same as for Exercise 14.

Procedure. — This experiment should be completed at one session unless it is certain that the pendulum will not be disturbed.

(1) Make a pendulum about one meter long. Its exact length is not important, but the same length must be preserved throughout the experiment.

(2) Determine the time required for one vibration, as in the preceding experiment, the arc through which the pendulum swings being less than 6°.

(3) Start the pendulum swinging through an arc of about 60°, and determine the time for one vibration, as before.

(4) Determine the period, the arc being about 30°.

It is not sufficient in any case to find the time of one vibration by taking the time for 100 vibrations just once, but the average of at least three determinations should be taken.

The number of degrees in the arc can be determined approximately by comparing the chord of the arc with the length of the pendulum, remembering that when the chord of the arc equals the length of the pendulum the arc is 60°. Exact measurements of the arcs are not required.

Tabulate the data as follows:

LENGTH OF ARC	TIME OF BEGINNING	TIME OF ENDING	WHOLE TIME	TIME OF ONE VIBRATION

Find the average time for all arcs less than 6°; for all arcs about 30°; for all arcs about 60°; and compare the times of these three averages.

EXERCISE 16

MOMENT OF A FORCE

Purpose. — *To test the principle of moments, the law of the lever, and to study the relation of the weight of a body to its center of gravity* ~~(§§ 65, 107, 108, 109, 110)~~.

Apparatus. — A lever clamp having a knife edge and stand upon which the knife edge rests and turns freely ~~(Fig. 17)~~. A meter stick. A set of metric weights. A platform balance. A brass clip or rider with the meter stick.

Procedure. — (1) Weigh the meter stick with the brass clip.

(2) Slip the meter stick through the clamp and fix the knife edge exactly at the 50 cm. mark. If the meter stick will not exactly balance horizontally on the knife edge, place the brass clip upon it so that it will, and keep the clip in the same position throughout the experiment.

If the meter stick will balance without the clip, then the latter should be dispensed with and should not be weighed with the meter stick.

The center of gravity of the meter stick is just below the knife edge. Call it C.

(3) Suspend by a loop of thread a 100 g. weight W_1 on the right of the bar at a distance d_1 from C and suspend a 200 g. weight W_1 on the left at a point at which it will exactly balance the weight on the right. Record its distance from C under d_1. Find the moment of each force.

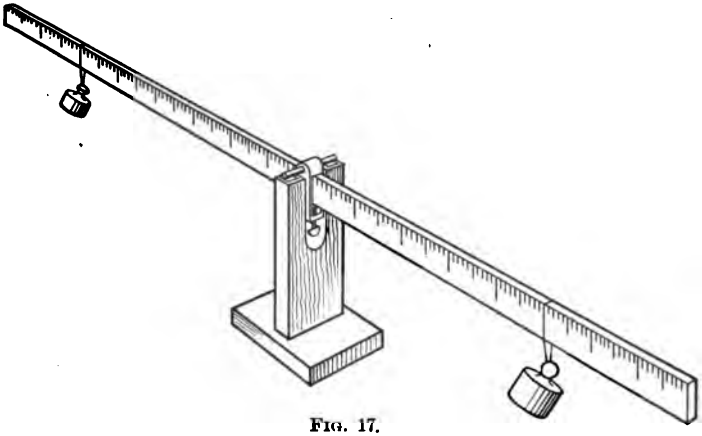


FIG. 17.

(4) Repeat the above, placing the first weight at another point on the bar.

(5) Suspend a 50 g. weight and a 100 g. weight at different points on the right of the bar, recording the respective weights and distances under W_1, d_1, and W_2, d_2, and find the point on the left where the 200 g. weight will exactly balance them. Find moment of the force on the left and the sum of the moments on the right.

(6) Repeat the above, using a 100 g. weight and a 50 g. weight at different points on the right and a 200 g. weight and a 20 g. weight on the left.

(7) Move the knife edge toward the left end of the bar, say 20 or 25 cm., and fasten it. Then find a point on the left where a 200 g. weight or a 100 g. weight will exactly balance the ruler. Record the weight of the ruler and the distance from C to the knife edge respectively as W_1 and d_1 on the right. Repeat this, placing the knife edge at another point. Record the results as follows:

WEIGHT OF METER STICK__________							
SIDE	W_1	d_1	MOMENT OF W_1 OR $W_1 \times d_1$	W_2	d_2	MOMENT OF W_2 OR $W_2 \times d_2$	SUM OF MOMENTS
1 Right							
Left							
2 Right							
Left							
3 Right							
Left							

Discussion. — The *moment of a force is its importance in producing rotation about an axis*, and its amount or measure is the *product of the force by the lever arm* on which it acts (§ 109). What relation do you discover between the moments of the forces on the right and those on the left? Those on the *right* which produce rotation in a *clockwise* direction are called **positive** moments, and those on the *left* which cause rotation in a *counter-clockwise* direction are called **negative** moments. What is the algebraic sum of all the moments on the bar? To what class does this lever belong? Show that the data taken illustrate the law of the lever.

EXERCISE 17

THE INCLINED PLANE

Purpose. — *To find the relation between the force P which moves a body up an inclined plane and the weight W which is moved* (§ 58).

Also to show that the general law of machines applies to the inclined plane (§ 118).

Apparatus. — An inclined plane consisting of a smooth board covered with plate glass (Fig. 18) and having a pulley at its upper end. A small car loaded with nails or other heavy material, or a metal cylinder for the weight *W*. A scale pan attached to the car by a stout cord. A platform balance. A set of metric weights. The table upon which the inclined plane is supported should be made exactly level by the help of a carpenter's spirit level.

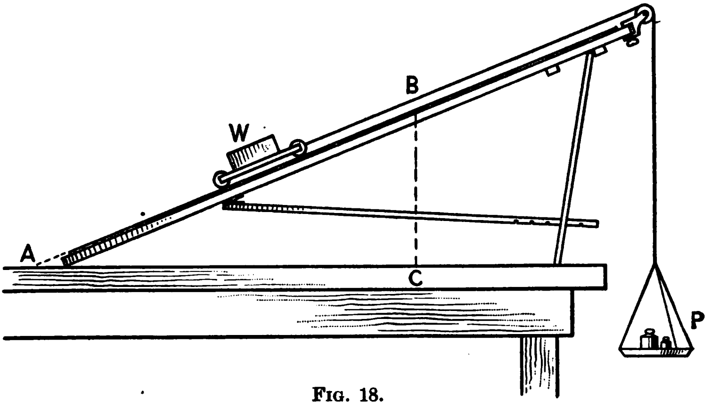


FIG. 18.

Procedure. — (1) Find the weight of the metal ~~car with its load~~, also of the scale pan.

(2) ~~Arrange the apparatus as shown~~ in ~~the figure~~, ~~and~~ Determine by several trials what weight in the pan is nec-

essary to pull the roller ~~car~~ up the plane *at uniform speed after it is started.* Give ~~the car~~ a little push to start it, but *keep the hands off the string and pan in making the test.*

(3) Likewise find what weight in the pan will allow the roller ~~car to~~ roll down the plane *at a uniform speed after it is started.* measure carefully the length of the plane AB,

(4) ~~Designate the intersection of the plane of the board with the plane of the table by A.~~ and the length BC. ~~This point may be found by placing the edge of a ruler on the plane and sliding it down until its~~ end ~~just touches the table. From~~ this point *A*, measure off on the plane a distance of 80 cm., designating the point reached on the plane by *B*. From *B*, by means of a square and a rule, measure the vertical distance to the table, designating this line by *BC*. *BC* will be the vertical rise of the car, or *W*, when it goes up the plane 80 cm., while at the same time the scale pan and weights, or *P*, fall vertically 80 cm.

(5) Draw in your notebook a diagram in which the distances *AB*, *BC*, and *AC* and the angle at *A* are correctly represented, and record on *AB* and *BC* the distances they represent.

Record the results as follows:

Weight of the car and its load, or *W*...... Weight of pan......				
Distance *AB*, or l =.......... Distance *BC*, or h =..........				
Trials	1	2	3	Average
Pan plus weights, car going up				
Pan plus weights, car going down				
One half the sum of the averages, or P = ...				
$\frac{W}{P}$ = ... $\frac{l}{h}$ = ... $W \times h$ = ... $P \times l$ = ...				

Discussion. — When the car is going up, the weight in the pan is greater than it should be by the amount of friction overcome; when the car is going down, it is less than it should be by the amount of friction overcome. Hence, taking one half of the sum of the two averages eliminates the friction and gives the true force necessary to move the car up the plane. One half the difference of the two averages gives the amount of the friction.

According to Newton's first law of motion, when the car has uniform speed, the two forces, the pan and weights and the weight of the car acting down the plane, exactly balance each other.

Compare the two ratios, $\frac{W}{P}$ and $\frac{l}{h}$. If they are equal as far as the sure figures go, you can form a proportion from them. State in words the meaning of such a proportion.

When the car moves up the plane 80 cm. the pan or power P falls 80 cm. Hence the power P does $P \times 80$ or $P \times l$, units of work. At the same time the car is lifted vertically a distance of BC, or h, and the work done upon it is equal to $W \times h$ ~~(§ 86)~~. How do these two quantities of work compare? What law is illustrated?

Compute the *efficiency* ~~(§ 104)~~ of the plane considered as a machine. This may be done by dividing $W \times h$, which is the useful work done, by $(P + F) \times l$. F represents the friction and hence $(P + F) \times l$ includes the useful work done by the pan and weights as well as the work wasted in overcoming friction.

Draw a vertical line on your diagram downward from the line AB of the right length to represent W. Resolve this line into two components, one perpendicular to AB and one on AB. Measure the component on AB and determine the force it represents. Compare it with P.

EXERCISE 18

ELASTICITY

Purpose. — *To show the relation between the bending of a ruler and the force applied to bend it* (§§ 141–143).

Apparatus. — A ruler or meter stick clamped firmly to a firm support (Fig. 19). The ruler has a pin inserted in its end as an index, and a hook near its free end from which a scale pan is suspended. A meter stick is supported vertically near the end of the ruler, or the mirror scale of the Jolly balance may be used in its stead. A set of weights.

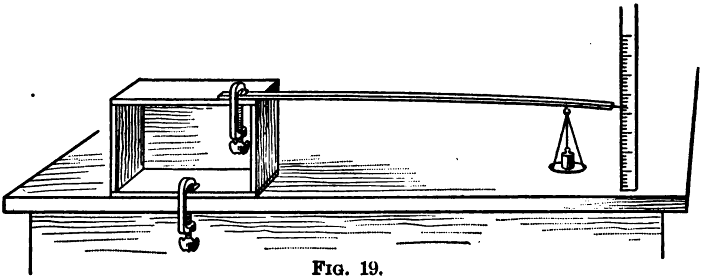


FIG. 19.

Procedure. — (1) Read the position of the pin or index on the scale, avoiding parallax, and estimating tenths of millimeters.

(2) Place a 100 g. weight in the pan and again read and record the position of the index. Then remove the weight and again note the position of the index. If it does not return to its original position, observe whether it does so after waiting a few moments.

(3) Repeat, using 200 g., 300 g., etc., up to 1000 g., always reading the position of the index after each load is removed.

Record the results as follows:

POSITION OF INDEX WITH NO LOAD	AVERAGE WITHOUT LOAD	POSITION WITH LOAD	DEFLECTION, OR D	LOAD, OR L	$\frac{D}{L}$

Discussion. — Are the numbers of the last column constant? If so, what does it signify?

Using the loads and deflections, plot upon coördinate paper a curve showing the relation between them.

Since the load and the elastic force of the ruler are in equilibrium, they are equal. What relation exists between elastic force of the ruler and the load? Is Hooke's law verified by this experiment (§ 143)?

CHAPTER III

MECHANICS OF FLUIDS

EXERCISE 19

DOWNWARD PRESSURE IN LIQUIDS

Purpose. — *To show the relation of downward pressure in a liquid to depth* (§§ 165, 167).

Apparatus. — A cylindrical glass jar about 8 cm. in diameter and 40 cm. deep, ~~having a paper scale pasted down its side~~. ~~This scale can be cut from cross-section~~ paper ruled in millimeters or in ~~twentieths~~ of an inch. A glass tube about 75 cm. long and 4 mm. inside diameter, bent as shown in Figure 20, the tube being filled with mercury at the bend to a depth of about 3 cm. A clamp for holding the tube, consisting of two pieces of wood each piece having a shallow groove across the middle of one side. These pieces are held together by a rubber band, the tube being placed in the groove between them.

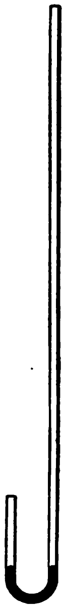


FIG. 20.

Procedure. — (1) The jar being nearly full of water, place the tube in the clamp and support it in the jar by resting the clamp across the top of the jar. The tube can now be moved easily up and down and will be held at any desired position.

(2) With the mouth of the tube about 15 cm. below the surface of the water, note the position of the surface of the water on the scale. To one

looking obliquely upward (Fig. 20) at this surface, it appears like a brilliant mirror. Raise the eye gradually until the line of sight just grazes the mirror-like surface, and then note its position on the scale.

(3) Note the height of the mercury surface in the short arm of the tube; that is, the point where the mercury and water meet in the tube. All the air must be removed from the short arm of the tube.

This measurement can be taken best by wrapping a band of paper with a straight edge about the jar and sliding it down until its upper edge is on a level with the mercury. Sight through the water to the edge of the paper on the opposite side. The paper may be held in place by a rubber band.

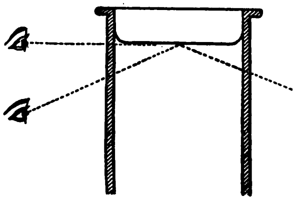


FIG. 21.

(4) In the same manner observe the height of the mercury in the long arm of the tube, *estimating tenths* of a division in this and all the other measurements taken.

(5) Move the tube down a few centimeters and repeat the above measurements, not omitting the first one, the surface of the water in the jar.

Record the data as follows:

SURFACE OF WATER	MERCURY IN SHORT ARM	MERCURY IN LONG ARM	DEPTH OF WATER	ELEVATION OF MERCURY	ELEVATION PER UNIT OF DEPTH

The quantity in the fourth column is the depth of water exerting pressure on the mercury, and is found by taking the difference between the quantities in the first two columns.

EXERCISE 20

LATERAL PRESSURE IN LIQUIDS

Purpose. — *To show the relation of lateral pressure in a liquid to depth.*

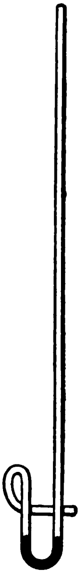


Fig. 22.

Apparatus. — Same as for Exercise 19 except that the tube is bent so as to open laterally, as shown in Figure 22.

Procedure. — (1) The procedure is, in general, the same as in the preceding exercise. In this case, however, the water and the mercury must not come together in the tube. The pressure of the water will be transmitted to the mercury by the inclosed air.

One measurement more than was taken in that exercise will be necessary, — the depth of the center of the lateral opening. To do this, measure to the upper edge of this arm and then add to this the radius of the tube, its diameter having been previously found by calipers.

The table for this exercise requires one additional column for the depth of the lateral opening.

EXERCISE 21

UPWARD PRESSURE IN LIQUIDS

Purpose. — *To show the relation of upward pressure in a liquid to depth.*

Apparatus. — Same as for the preceding exercise except that the tube opens downward, as shown in Figure 23.

Procedure. — (1) Proceed as in the last exercise;

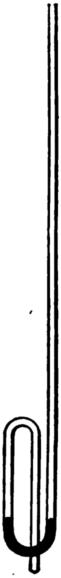


Fig. 23.

but instead of finding the position of the mouth of the tube, take that of the point where the air and water meet in the tube.

Use a table similar to that of the last exercise.

In the last three exercises, using the pressures and the depths as coördinates, show graphically the relation between them.

What does a comparison of the last column in each of the tables of the last three exercises with one another teach?

Do you see how the results of these exercises may be used in comparing the density of mercury with that of water? Find the average of the last column in each of the three tables.

EXERCISE 22

THE BAROMETER

Purpose. — *To learn to read the barometer* (§§ 170–176).

Apparatus. — A barometer with a thermometer attached. A thermometer outside the building.

Procedure. — (1) Read the thermometer attached to the barometer at once, before it is influenced by the body of the observer.

(2) Tap the instrument gently near the upper level of the mercury to counteract the adhesion of the mercury to the glass, which sometimes prevents small movements of the mercury.

(3) Adjust the mercury in the cistern to its proper level. To do this, turn the screw *O* at the bottom of the instrument until the mercury at *q* (Fig. 24) just touches

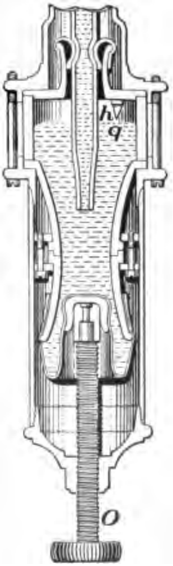


FIG. 24.

the ivory pointer *h*. Why is this adjustment necessary (§ 173)?

(4) Adjust the vernier to the top of the mercury by turning the milled head *D* (Fig. 25). Its lower edge should be tangent to the top of the mercury, so that a white background can be seen on either side but not at the center of the mercury surface. Read the height in both inches and centimeters.

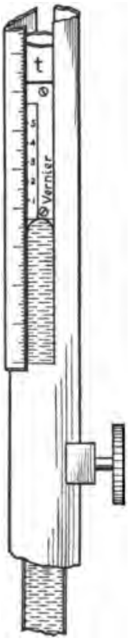


Fig. 25.

(5) Take the temperature by the outside thermometer.

(6) In Table 8, Appendix, find the correction for temperature, using that found by the thermometer on the instrument. If the temperature is above 32° F. or 0° C., subtract this correction; otherwise add it. Why? (What effect does temperature have on the density of mercury?) (§ 175.)

(7) In Table 9, Appendix, find the correction for elevation above sea level, using the temperature given by the outside thermometer. Add this. Why? (Ascertain the elevation from the instructor.) (§ 175.)

(8) Make observations for several consecutive days at the same hour of the day, and record the results as follows:

Date	Hour	Temperature of Barometer	Temperature Outside	Height in Inches	Height in Centimeters	Correction for Temperature	Correction for Elevation	Corrected Height	United States Report

(9) Obtain the United States Signal Service report for the same days at the nearest station, and place them in the last column. Compare your results with them, and explain any discrepancy if you can.

EXERCISE 23

BOYLE'S LAW

Purpose. — *To study the effect of change of pressure on the volume of a gas, or to verify Boyle's Law* (§ 177). Melde's Method.

Apparatus. — A piece of barometer tubing about 110 cm. long, sealed at one end (Fig. 26). This tube contains near its center a thread of mercury *M* about 45 cm. long which incloses some air *BF* between it and the closed end of the tube. A narrow strip of paper graduated in centimeters and millimeters is attached by paste or glue to the tube extending from its sealed end up beyond the mercury. This paper scale enables us to read the length of the air column inclosed by the mercury. Since the cross section of the tube is uniform, this length is taken as the volume of the air. The tube is held at its center by a clamp *L* which turns on a horizontal axis so that the tube can be turned through

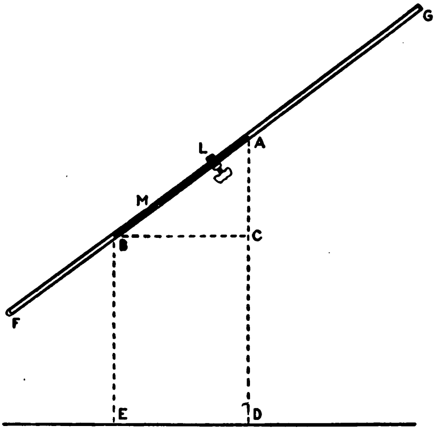


FIG. 26.

an angle of 180°. A barometer. The table upon which the work is done should be exactly level.

When the tube is vertical, *G* being up, the pressure on the air *BF* is measured by the barometer reading + the length of the mercury thread *AB*. When the tube is vertical, *G* being down, the pressure on *BF* is measured by the barometer − *AB*.

When the tube is inclined and *A* is higher than *B*, the pressure is the barometer reading + the difference between *AD* and *BE*, or *AC*; but when *A* is lower than *B*, the pressure is the barometer reading − the difference between *AD* and *BE*. This follows because pressure of any liquid depends on its depth, and the depth of the mercury is the distance *AC*. (It might be better to call the difference between *AD* and *BE* negative when *A* is lower than *B*, and then always add it, algebraically, to the barometer reading.)

Procedure. — (1) Read the barometer in centimeters, not making any corrections for temperature or elevation, because the temperature of the mercury of the barometer is assumed to be the same as that in the tube.

(2) Place the tube in a vertical position with the open end *G* up, and measure by the meter stick the heights of *A* and *B* above the table. Also read the length or volume of the air *BF* by the paper scale.

(3) Turn the tube carefully by the clamp *L* a few degrees and again measure *AD*, *BE*, and *BF*.

Continue this process until the tube is again vertical with *G* down. You should have about 10 different readings. For one of them let the tube be in such a position that *BF* is just twice what it was at first; for another, three times what it was at first; and for another, four times what it was at first.

Record the results as follows:

Barometer Reading__________					
Volume of Air BF or V	AD	BE	$AD - BE$	Pressure P	$P \times V$

Discussion. — It is a law of mathematics that when the product of two variables is constant, the two quantities are inversely proportional. Is the product $P \times V$ constant, at least as far as the sure figures?

Another way to consider this is to notice whether the pressure is $\frac{1}{2}$ as great as at first when the volume is 2 times as great; $\frac{1}{3}$ as great when the pressure is 3 times as great; etc.

EXERCISE 24

DENSITY OF WATER

Purpose. — *To determine the density of water.*

Apparatus. — A burette. A small beaker. A balance. A thermometer.

Procedure. — (1) See that the beaker is clean and dry, and then weigh it.

(2) Measure out in the beaker from 20 to 40 cc. of distilled water by means of a burette.

To do this, fill the burette with water, carefully wiping off any on the outside of the instrument. Then allow some water to run out of the burette by the stopcock into a waste dish until the surface of the water is below the zero at the top and all the air bubbles are driven out of the lower end of the burette. Note with great care the position of the surface of the water on the scale, and then allow the water to be measured to flow into the beaker.

Read again the amount of water in the burette; and by subtracting the first reading from the last obtain the volume of water in the beaker.

(3) Weigh the beaker and water and then take its temperature (see note in Exercise 51 in regard to reading the thermometer). Stir the water carefully with the thermometer until the mercury is stationary before reading the temperature.

(4) Find the weight of the water and calculate its density as in Exercise 8.

Record the data as follows:

Weight of empty beaker --
Weight of beaker and water -----------------------------------
Weight of water taken ---
Temperature of the water --------------------------------------
First reading of the burette------------------------------------
Second reading of the burette ---------------------------------
Volume of water taken ---
Density of water found ---
Density of water at given temperature (see Table 4, Appendix)------
Error ------------------ Percentage of error -----------------

If time permits, the average of several determinations should be found and then the error and the percentage of error determined.

EXERCISE 25

BUOYANT FORCE. THE PRINCIPLE OF ARCHIMEDES

Purpose.—*To find the relation between the loss of weight of a body immersed in a liquid and the liquid it displaces.*

Apparatus.—A beaker filled with distilled water. A Jolly balance. A piece of fine waxed thread. The metallic cylinder whose density was determined in Exercise 9.

Procedure.—(1) Taking the cylinder whose weight and volume were found in Exercise 9, find its weight while it is immersed in distilled water. To do this, either suspend the cylinder from the under side of the balance pan by a thread; or if the balance has a pan of glass, place it in that. *In the latter case the index reading with no load in the pan must be taken with the pan in water also.* Why?

Record the data as follows:

Weight of the cylinder in air ....
Weight of the cylinder in water ....
Loss of weight in water ....
Volume of the cylinder ....

Discussion.—What volume of water was displaced by the cylinder?

What weight of water was displaced by the cylinder? Why? See Exercises 9 and 24.

How does the loss of weight in water compare with the weight of the water displaced?

How many times denser is the cylinder than water?

The answer to the last question will be the **specific gravity** of the substance composing the cylinder. What is specific gravity? (§ 16.)

How can the volume of the cylinder be determined from the data of this exercise and the preceding exercise?

Compare the volume so obtained with that obtained in Exercise 9, and determine the error and the percentage of error assuming this to be correct.

EXERCISE 26

SPECIFIC GRAVITY OF SOLIDS DENSER THAN WATER

Purpose.—*To determine the specific gravity and the density of brass or other metal* (§§ 184, 188–189).

Apparatus.—A Jolly balance or a beam balance. A glass of distilled water. A piece of waxed thread. A piece of brass, or other substance, whose specific gravity is to be determined.

Procedure. — (1) Weigh the solid in air.

(2) Weigh the solid while it is immersed in distilled water. To do this, either suspend it by a thread from the under side of the balance pan, or if the balance has two pans, one above the other, place the solid in the lower pan to weigh it in water. *In the latter case the lower pan should be immersed in water to about the same depth throughout the entire experiment.*

From its weight in air and in water compute the density of the solid and compare with that of water in accordance with the principles of the last exercise.

Remarks. — To correct for the error due to the fact that the water used is not at 4° C., multiply the density found by the density of water at the temperature at which it was used. This may be found in Table 4, Appendix. To find the amount of the error of your results, compare them with those given in Table 3.

When a Jolly balance is used, the elongations of the spring alone may be used, the modulus of the spring not being considered. Thus in the above exercise, if a represents the index reading with no load, b the index reading with the load in air, and c that with the load in water, then $(b-a)$ divided by $(b-c)$ will equal the specific gravity of the substance.

This may be explained as follows, m representing the modulus of the spring:

$$m(b-a) = \text{weight in air.}$$
$$m(c-a) = \text{weight in water.}$$
$$m(b-a) - m(c-a) = m(b-c) = \text{loss of weight in water.}$$

Hence, $m(b-a) \div m(b-c) = (b-a) \div (b-c) =$ specific gravity.

LOWER DIVISION

How can specific gravity be reduced to density, whether the density be expressed in the metric or in English units? The density of water is 0.577 oz. per cubic inch. Reduce the specific gravities found to densities in both systems.

Record the data as follows:

Substance	*a*	*b*	*c*	Specific Gravity	Density in Grams per Cubic Centimeter	Density in Ounces per Cubic Inch

EXERCISE 27

SPECIFIC GRAVITY OF SOLIDS LESS DENSE THAN WATER

Purpose. — *To determine the specific gravity and the density of paraffin or other substances lighter than water.*

Apparatus. — A Jolly balance or a beam balance. A small cylinder of brass to be used as a sinker, having a sharp needlelike point at one end and a hook at the other (Fig. 27). A thermometer. Distilled water. A piece of wax, or other substance lighter than water, whose specific gravity is to be found.

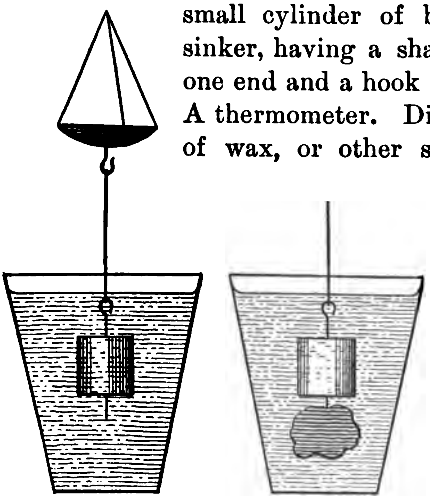


Fig. 27.

Procedure. — (1) Attach the cylinder to the under side of the balance pan by a fine wire about 5 cm. long, the point of the cylinder being down.

(2) Immerse the

cylinder in water, and keep it immersed throughout the entire exercise.

(3) If a beam balance is used, counterpoise the cylinder with shot. If a Jolly balance is used, take the index reading with the cylinder in water.

(4) Place the wax in the scale pan above the cylinder and weigh it, or take the index reading.

(5) Fasten the wax to the cylinder by thrusting the point of the cylinder into it, and immerse wax and cylinder in water.

(6) If a beam balance is used, place sufficient weights in the pan to which the cylinder is attached to exactly restore the equilibrium. These weights will equal the weight of the water displaced by the wax. If a Jolly balance is used, take the index reading again.

The remarks of the last exercise in regard to correction for temperature and method of calculation will apply to this exercise. In fact, with the Jolly balance the operations and calculations are exactly the same as in the last exercise.

When a beam balance is used, the weight in air divided by the weights added to restore the equilibrium will give the specific gravity. Why?

Use the same tabular form as for the last exercise.

EXERCISE 28

SPECIFIC GRAVITY OF LIQUIDS BY WEIGHING A SOLID IN THEM

Purpose. — *To determine the specific gravity and density of alcohol or other liquids* (§ 190).

Apparatus. — A Jolly balance or a beam balance. A piece of a glass rod or a glass stopper for a sinker. A liquid whose specific gravity is to be determined, such as glycerine, benzine, alcohol, kerosene, or sulphuric acid. A thermometer.

A. WITH A BEAM BALANCE

Procedure. — (1) Find the weight of the sinker in air.

(2) Find the weight of the sinker in water, suspending it by a thread, or if the liquid is an acid, by a platinum wire, from the under side of the balance pan.

(3) Dry the sinker and find its weight in the liquid.

(4) Take the temperature of the water.

B. WITH A JOLLY BALANCE

(1) Take the index reading with the sinker in air, *a*.

(2) Take the index reading with the sinker in water, *b*.

(3) Take the index reading with the sinker in the liquid, *c*.

(4) Take the temperature of the water.

If the liquid and the water have been standing for some time in the same room, the temperature of both may be assumed to be the same without serious error.

Before transferring the sinker from one liquid to another, always wash and dry it carefully.

Record the results as follows:

SUBSTANCE	*a*	*b*	*c*	SPECIFIC GRAVITY	DENSITY IN GRAMS PER CUBIC CENTIMETER	DENSITY IN OUNCES PER CUBIC INCH

Discussion. — If m represents the modulus of the spring, then $m(a - c)$ = loss of weight of sinker in water and $m(a - b)$ = loss of its weight in the other liquid. By the principle of Archimedes these losses are the weights of equal volumes of the two liquids. Hence, $m(a - c) \div m(a - b)$ or $(a - c) \div (a - b) =$ the specific gravity of the liquid.

EXERCISE 29

SPECIFIC GRAVITY BOTTLE

Purpose. — *To determine the specific gravity of liquids by means of a specific gravity bottle* (§ 190).

Apparatus. — A balance. A specific gravity bottle. Alcohol. Bellows, to which a glass tube is attached by a rubber tube. A thermometer. A shallow pan containing tepid water. A liquid whose specific gravity is to be determined.

Procedure. — (1) See that the bottle is thoroughly clean and dry. In cleaning the bottle, rinse it finally with distilled water and then with alcohol, after which dry it by passing a stream of air through it by means of the bellows and the glass tube. If the air is warmed somewhat by holding the glass tube in the flame of a Bunsen burner, the bottle will be dried more quickly and thoroughly.

(2) Weigh the empty bottle, or take the index reading with the empty bottle in the pan.

(3) Fill the bottle with distilled water. See that no air bubbles remain in the bottle, and that it is full to the top of the stopper.

(4) Have the shallow pan ready with some water in it at about 30° C. Allow the bottle to stand in this for a few minutes, until the water in it has come to some definite temperature, which will be indicated by a thermometer placed in the pan. Record this temperature at the time the bottle is taken from the water. This temperature should be above that of the room, say 25° to 30° C.

(5) Wipe the bottle dry on the outside and weigh it, or take the index reading with it in the Jolly balance pan.

(6) Empty and dry the bottle and fill it with the liquid. Treat this in the same way the bottle full of water was treated, bringing it to the same temperature by adding warm or cold water to the water in the pan, as the case may require, and stirring it thoroughly.

(7) Weigh the bottle full of the liquid, or take the index reading with it in the pan.

(8) Return the liquid to the bottle from which it was taken, and thoroughly cleanse the specific gravity bottle before putting it away.

If a is the index reading for the empty bottle, b for the bottle full of water, and c for the bottle full of the liquid, then $(c - a)$ divided by $(b - a)$ will be the specific gravity of the liquid.

Correct for temperature as in the preceding exercise.

Record the results in a form similar to that used in the last exercise.

NOTE. — The fact that the bottle does not remain full after being taken from the water is of no consequence. It is due to contraction. Equal volumes are taken at the temperature of the water in the pan.

EXERCISE 30

SPECIFIC GRAVITY OF LIQUIDS BY HARE'S METHOD OF BALANCED COLUMNS

Purpose. — *To determine the specific gravity of a liquid by comparing the height of a column of it with that of a column of water, when both are supported by the same pressure.*

Apparatus. — A Y-tube, to which two glass tubes about 50 cm. long and 8 mm. in diameter are joined by short pieces of rubber tubing. A rubber tube about 30 cm. long, and closed by a pinchcock, is attached to the third branch of the Y-tube. Two tumblers, one containing dis-

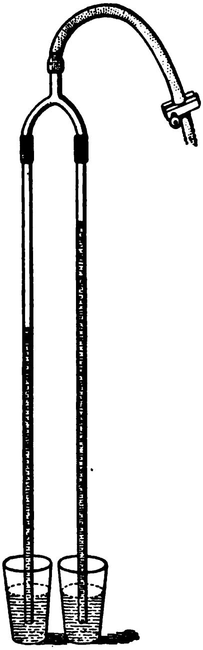


FIG. 28.

tilled water and the other the liquid to be tested (see Fig. 28). A thermometer.

Procedure. — (1) Support the tubes in a vertical position, with the two glass tubes standing one in each tumbler.

(2) Raise the liquids in the tubes to a height of 30 or 40 cm. by a partial exhaustion of the air through the rubber tube, and then close the tube *air-tight* by the clamp.

Watch the liquids in the tubes for a few moments to see whether the liquids fall or not. If they do, it shows that the tube is not closed air-tight by the clamp.

(3) Measure the vertical height of the two columns above the surfaces of the liquids in the tumblers.

(4) Make three different sets of measurements, changing the heights of the columns each time.

Record the results as follows:

LIQUID	HEIGHT OF WATER COLUMN	HEIGHT OF LIQUID COLUMN	SPECIFIC GRAVITY	DENSITY IN GRAMS PER CUBIC CENTIMETER	DENSITY IN OUNCES PER CUBIC INCH

Discussion. — Since each column of liquid is supported by the same pressure, and since the pressure each exerts is proportional to its height and density (§ 68), we can compare the density of the liquid with that of water by dividing the height of the water column by that of the other liquid.

CHAPTER IV

SOUND

EXERCISE 31

VIBRATION RATE OF A TUNING FORK

Purpose. — *To determine the vibration rate of a tuning fork* (§ 192).

Apparatus. — A tuning fork making from 100 to 300 vibrations per second. A pendulum of a known rate of vibration, and arranged to make and break an electric circuit at every swing by a mercury contact. A relay. An induction coil. Two batteries. An apparatus, shown in Figure 29, in which *A* is a metallic drum, about 12 cm. in diameter and 15 cm. long, supported on a shaft that has a crank at one end. A thread is cut on one end of this shaft, so that when the drum is revolved it moves longitudinally. A small flexible point *c* is cemented to the end of one of the prongs of the fork *HF*, a piece of an old hairspring from a watch being used for it. A bass-viol bow. A candle or an ordinary gas jet.

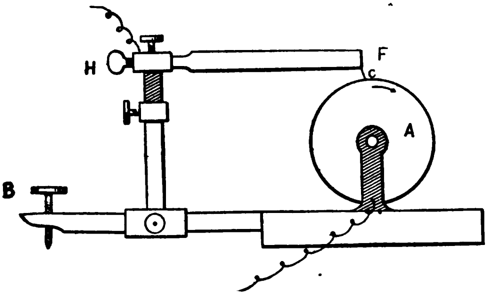


Fig. 29.

Procedure. — (1) Gum one end of a strip of paper long enough to reach around the drum, and as wide as the drum is long, and fasten it tightly around the drum.

(2) Smoke the paper evenly and thinly by holding a candle flame, or a gas jet from a fish-tail burner, against it, and revolving the drum rapidly.

(3) Fix the fork in position so that the point *c* just touches the paper. The screw *B* affords a fine adjustment for this purpose. This adjustment should be made with great care.

(4) Connect one terminal of the secondary of the induction coil with the fork, and the other with the drum. Connect the primary of the coil with the battery and with the contact maker of the relay, and the relay coil with the other battery and the pendulum. The induction coil and the battery used with it must be large enough to produce a spark at *c* to penetrate the paper at each swing of the pendulum. Turn the screw up against the vibrator of the induction coil so that it can vibrate only a very little.

(5) Set the fork in vibration by the bow, and turn the drum with a steady motion in the direction shown by the arrow. Turn the drum so that there will be at least two sparks at every revolution.

(6) Remove the paper from the drum by cutting it across near the lap, being careful that the smoked surface does not touch anything. Pass the paper through shellac varnish, and when it is dry count the number of vibrations from one hole in the paper to the next but one; that is, the number made during one complete vibration of the pendulum. It is almost impossible to adjust the pendulum so that the times taken for the swing of the pendulum on each side of the mercury contact will be equal to each other, hence the necessity for counting the vibrations for two half periods. It will assist the counting to mark every tenth vibration.

Dividing the number of vibrations counted by the time of one complete vibration of the pendulum will give the number of vibrations of the fork per second.

Several trials can be made on one paper. Record the results of two or three trials, and take the average of the several results. Fasten the paper in your notebook.

EXERCISE 32

VELOCITY OF SOUND

Purpose. — *To measure the velocity of sound by means of a resonant air column and a fork of a known rate of vibration. Or, to determine the frequency of a tuning fork by means of a resonant air column and the known velocity of sound.*

Apparatus. — A tuning fork having a known frequency — 100 to 300. A thermometer. A glass tube (Fig. 30) about 3 cm. in diameter and a meter long. This tube is connected at the bottom by a rubber tube and a siphon with a bottle of water, as shown in the figure. The tube is clamped in a vertical position and a metric scale is placed beside it. A small mallet made of a rubber stopper and a wooden rod. To fill the bottle and siphon, place it on the floor below the tube and pour water into the tube.

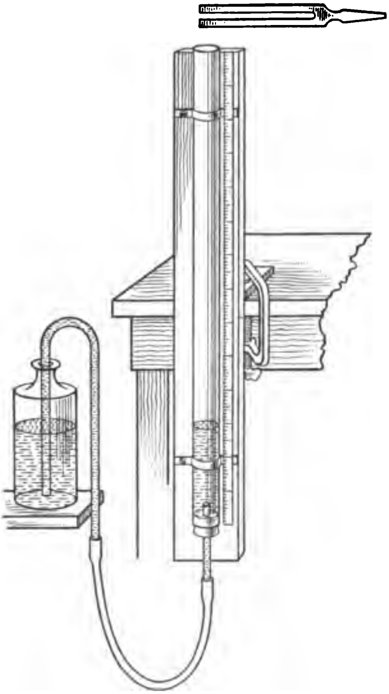


FIG. 30.

Procedure. — (1) Let one person hold the fork at the mouth of the tube, tapping it lightly now and then with the mallet to keep it in vibration, while another person changes the level of the water in the tube by raising and lowering the bottle. Find in this way the shortest depth of the air column that gives the best resonance, taking the average of several trials.

(2) If the tube is long enough, resonance will occur with an air column about three times as long as the first. In the same manner as before locate the position of the water for this second resonance.

(3) Measure the diameter of the tube.

(4) From a thermometer suspended near the tube determine the temperature of the air, and calculate the velocity of sound. $v = 331.4 + .6 \times t$. (§ 211.)

Record the results as follows:

Length of Air Column, 1st Resonance	Length of Air Column, 2d Resonance
1 2 etc.	
Av. =	
Wave length	
Diameter of tube..........	Correction..........
Frequency of fork..........	Temperature of air..........
Velocity of sound (by experiment)..........	
Velocity of sound ($331.4 + .6\,t$)..........	
Error..........	% of error..........

Discussion. — This experiment enables us to determine the length of the sound waves. The air column for the first resonance, or one third of that for the second resonance, gives nearly the quarter wave length; this should be corrected by the addition of .7 of the diameter of the tube (§§ 218–219), and then multiplied by 4. Knowing the wave length and the frequency of the fork, the velocity can be calculated, or knowing the wave length and the velocity, the frequency of the fork can be calculated, since

$$v = n \times l \text{ or } n = \frac{v}{l}. \quad (\S\ 198.)$$

EXERCISE 33

VELOCITY OF SOUND IN SOLIDS. KUNDT'S METHOD

Purpose. — *To determine the velocity of sound in brass or glass* (§§ 203, 205, 207, 211, 212, 218, 219).

Apparatus. — A glass tube *T* (Fig. 31) about 1 m. long and 4 cm. in diameter. This tube is closed by a cork piston *P*, which is moved in and out by the rod *R*. The other end of the tube is closed with thin sheet rubber stretched over it and held in place by a rubber band. Some fine dry cork dust made by rubbing a baked cork on sandpaper is distributed along evenly within the tube. A brass rod *D* about 1 m. long and 1 cm. in diameter having

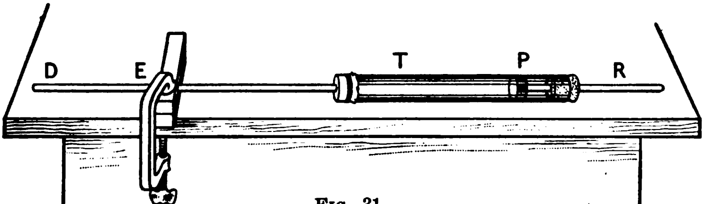


FIG. 31.

a disk of cardboard glued to one end. This rod is clamped between two strips of wood at its center and fastened firmly to the table by an iron clamp. A piece of cloth or soft leather covered with powdered rosin. A thermometer.

Procedure. — (1) Support the glass tube as shown in Figure 31 so that the cardboard disk on the end of the rod rests lightly against the sheet rubber. Place the thermometer near the tube.

(2) Stroke the rod from the center towards its free end with the cloth. It will give a high, clear note; and when the air column in the tube is of the proper length, it will set the cork dust into violent agitation.

(3) Vary the length of the air column by changing the position of the cork piston until the agitation of the dust is greatest. It will gather into groups of parallel ridges with unoccupied spaces between the groups. When the air column is properly adjusted in length, there will be an exact whole number of these groups, all of equal length. If the adjustment is not exact, the two end groups may not be perfect.

(4) Measure the length of the air column and count the number of groups. The length measured, divided by the number of groups measured, will give the length of one group. If the end groups are imperfect, do not measure or count them.

(5) Measure the length of the brass rod, and take the temperature of the air near the tube.

(6) To find the velocity of sound in glass, substitute a thick-walled glass tube about 1 m. long and 1 cm. in diameter for the brass rod, and repeat the above operations, using a damp woolen cloth to stroke the glass. The velocity of sound in wood, iron, or other substances can be found by the same method.

The average of several determinations should be taken.

Record the results as follows :

Length of Air Column	Number of Groups	Length of One Group, l	Length of brass rod, L
			Average of l
			$L \div l =$
			Temperature
			Velocity of sound in air
			Velocity of sound in brass

Discussion. — When the rod is set in vibration, the same rate of vibration is communicated to the air of the tube, and the sound is reënforced by the air column. There are as many vibrating air columns as there are *groups* of cork-dust ridges. The points midway between the different groups are places of no vibration, or nodes. As in the previous exercise the distance from the water, or place of no vibration, to the mouth of the tube, or place of greatest vibration, is one fourth of a wave length ; so in this, the distance from a node to the middle of a group is one fourth of a wave length, or the distance from one node to the next is one half of a wave length in air. Likewise the distance from the center of the brass rod to its end is one fourth of a wave length in brass, or the whole rod is one half a wave length long. Hence the wave length in brass for a given rate of vibration will be as many times as long as a wave length in air for the same rate of vibration as the length of one group is contained in the length of the rod. This ratio of wave lengths will also be the ratio of velocity of sound in brass to that in air, or the velocity of sound will be as many times greater in brass than in air as the wave length in brass is greater than that in air. Calculate the velocity of sound in air for the temperature taken, and then from the data of this exercise calculate the velocity of sound in brass.

EXERCISE 34

SCALE RATIOS

Purpose. — *To illustrate the relation between pitch and vibration frequency and to determine ratios or intervals between the notes of the diatonic scale and the keynote* (§§ 231, 233, 234).

Apparatus. — A siren consisting of a disk of brass or cardboard with eight concentric circles of holes, mounted on an electric motor or on a whirling table. A bellows fitted with a rubber tube, into the end of which a glass tube is inserted.

Procedure. — (1) Count the number of holes in each circle, beginning with the inner circle.

(2) Express the number of vibrations that each circle will produce when the disk is rotating and a jet of air is directed at each circle in succession. To do this, let n denote the number of rotations per second made by the disk. Each puff of air as it passes through a hole may be considered a vibration; and, therefore, there will be as many vibrations per second for any circle as there are holes in the circle multiplied by n, for example, if there are 24 holes in the first circle, 24 n will express the number of vibrations per second for that circle.

(3) Express the ratio of the number of vibrations per

second produced by each circle to the number produced by the inner circle in common fractions reduced to their lowest terms. Since *n* is a common factor in each of these, it will cancel out; and hence *n*, or the rate of rotation, does not need to be known.

(4) Set the disk in rotation; and when it has attained a uniform speed, direct a jet of air against each circle of holes in rapid succession, beginning with the inner circle. Be careful that the tube does not touch the disk. Designate the tones produced by the customary names. (Instead of using a bellows to produce the jet of air, place the rubber tube in the mouth and blow air from the lungs through the holes of the disk.)

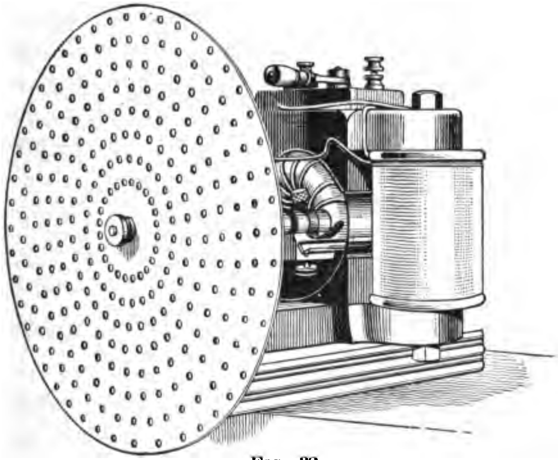


FIG. 32.

(5) Set the disk in rotation and direct a jet of air at a single circle of holes while the rate of rotation is increasing. What relation between vibration rate and pitch does this illustrate?

Record the results as follows:

Circle	1	2	3	4	5	6	7	8
Number of holes								
Names of the notes								
Vibration frequency								
Ratios of frequencies								
Intervals between successive notes								

Discussion. — These ratios determined by this experiment, if the circles have the correct number of holes, are the *scale ratios* or the intervals between the keynote and the other notes of the diatonic scale. Note the number of different intervals in the scale (§ 233): the major tones, the minor tones, and the major semitones.

EXERCISE 35

VIBRATIONS OF STRINGS. LAW OF LENGTH

Purpose. — *To determine the relation between the length of a string and its vibration frequency.*

Apparatus. — A sonometer ~~(Fig. 33)~~ fitted with a single string and having three bridges. A guitar or other stringed instrument may be used.

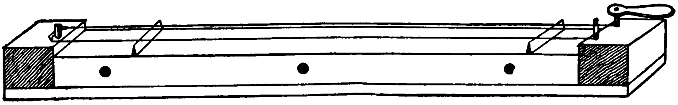


FIG. 33.

Procedure. — (1) Place the two bridges under the wire at some known distance apart, as 80 or 100 cm. Pluck the wire with the finger and use the tone produced as the keynote, or *Do*, in the following operations.

(2) Place the third or movable bridge under the wire

between the two bridges at such a point that the wire will give the note *Re*. This position is to be found by trial by the aid of the ear. The whole wire should be sounded frequently to aid the ear in finding the correct point. Measure the length of the wire giving the note *Re*.

(3) In like manner determine the lengths for the remaining notes of the scale.

(4) Repeat the operation several times with the same length of wire for the *keynote*, measuring this length now and then to see that the bridges are not out of place. Find the average of the lengths obtained for each of the notes of the scale.

(5) Find the ratio of each of the average lengths obtained to the length of the wire for the keynote, expressing the ratios decimally.

(6) Express decimally the reciprocals of the scale ratios found in the last exercise, and compare them with the ratios just found.

Record the data as follows:

NOTES	DO	RE	MI	FA	SOL	LA	SI	DO
Lengths of wire, 1st trial 2d trial 3d trial etc.								
Average of lengths								
Ratio of average lengths to length of keynote								
Reciprocals of scale ratios								
Error in each case								
Percentage of error								

Discussion. — The relation between the lengths of a string and its frequencies is shown by comparing the ratios of the lengths with the ratios of their frequencies.

Compare these ratios and state in words what they mean. Illustrate by using two notes as *Do* and *Mi*.

Corollary to the First Law. — *The lengths of two strings in unison are directly proportional to the frequencies of the two strings when their lengths are made equal.*

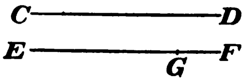


Fig. 34.

Proof. — Let CD and EF (Fig. 34) be two strings equal in length, and let EG, a part of EF, be in unison with CD.

(1) $\frac{\text{Frequency of } EG}{\text{Frequency of } EF} = \frac{\text{Length of } EF}{\text{Length of } EG}$ by the first law of strings.

(2) Frequency of CD = Frequency of EG by hypothesis.

(3) Length of CD = Length of EF by hypothesis.

Substituting these values in the proportion, we have

(4) $\frac{\text{Frequency of } CD}{\text{Frequency of } EF} = \frac{\text{Length of } CD}{\text{Length of } EG}$. Q. E. D.

This principle is of great use in proving the other laws of strings upon the sonometer.

EXERCISE 36

FREQUENCY OF A FORK

Purpose. — *To determine the vibration frequency of a fork by comparing it with a standard fork by means of a vibrating string.*

Apparatus. — A sonometer fitted with a single wire. A tuning fork No. 1 of a known rate of vibration and another fork No. 2 whose frequency is to be determined.

Procedure. — (1) First find the length of the wire which is in unison with the standard fork by changing the length of the wire until there are no beats when the two are sounded together. Call this length L_1.

(2) Without changing the tension of the wire, find in the same way a length of the wire in unison with the fork whose frequency is unknown. Call this length L_2.

Record the results as follows:

Frequency of Standard Fork No. 1, V_1 = ---------

TRIALS	1	2	3	AVERAGE
L_1				
L_2				

Frequency found for Fork No. 2, V_2 = ---------

The frequency of fork No. 2 is found by proportion according to the law of Exercise 35, as follows: $V_1 : V_2 = L_2 : L_1$.

THE TENSION BALANCE FOR THE SONOMETER

The tension balance (Fig. 35) is a small steel lever attached at one end of a sonometer (Fig. 36). The wires of the sonometer are attached to the knife-edges *A* and *B* by rings grooved on the inner circumference and the balance rests against another knife-edge or fulcrum *F*. When the fulcrum is at notch No. 1, which is exactly midway between *A* and *B*, the two wires are under equal tension; when the fulcrum *F* is at some other notch as at 4, the tension on the wire at *A* is to the tension on wire at *B* as the length *B* to 4 is to the length *A* to 4 according to Exercise 13 (§§ 55, 107).

EXERCISE 37

VIBRATION OF STRINGS. LAW OF DIAMETER

Purpose. — *To determine the relation between diameters of wires and their vibration frequencies* (§ 245).

Apparatus.—A sonometer fitted with two strings of piano wire of different diameters. These wires are attached to the sonometer by means of a tension balance (Fig. 36), the fulcrum *F* being at notch 1 so that the two wires are under equal tension. A micrometer screw. Three bridges.

Procedure.—(1) Measure the diameters of the wires by the micrometer screw. Take several different measurements of each wire at different places, recording the diameter of the smaller wire under *d* and of the larger under *d'*. Find the average of the different measurements.

(2) Take some measured length of the smaller wire, as 100 cm. (designated by *l* in the table) and find a length *l'* of the larger wire which is in unison with it, *i.e.* has the same pitch. The student can use to advantage in doing this both resonance and beats (§§ 216, 223). As the correct length is approached the beats become fewer and fewer, if both strings are sounding; or if one is sounded a few seconds and then silenced, the other will be found vibrating, the resonance being stronger the nearer the correct length is attained.

Repeat this with different lengths for *l*, and find the ratio in each case of *l'* to *l*.

Record the results as follows:

d	d'	l					
		l'					
		$\frac{l'}{l}$					
		Average of $\frac{l'}{l}$ = ...			$\frac{d}{d'}$ = ...		

Discussion. — According to the corollary (§ 246), page 82, the ratio of l' to l equals the ratio of the frequencies of the two strings when their lengths are equal. $\frac{l'}{l} = \frac{n'}{n}$, l', n', and d' being respectively the length, frequency, and diameter of the larger wire and l, n, and d of the smaller wire.

Compare the two ratios $\frac{l'}{l}$ and $\frac{d}{d'}$, remembering that an equality of ratios is a proportion and that what is true of $\frac{l'}{l}$ is also true of $\frac{n'}{n}$. State in words what your results prove.

NOTE. — Since the volumes of the two wires, the lengths being equal, are to each other as the squares of their diameters, their weights must be also. Hence, $\frac{d}{d'} = \sqrt{\frac{w}{w'}}$, w and w' being the respective weights of equal lengths of the two wires. What is the relation between the vibration rates of the two wires and their weights?

EXERCISE 38

VIBRATION OF STRINGS. THE LAW OF TENSION

Purpose. — *To determine the relation between the vibration frequency and the tension of a vibrating string* (§ 245).

Apparatus. — A sonometer fitted with a Ritchie tension balance (Fig. 35) and two strings of piano wire of the same diameter. Three bridges. A verniered caliper, or dividers and diagonal scale.

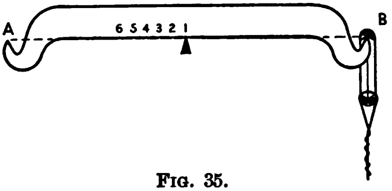


FIG. 35.

Procedure. — (1) Measure very carefully the distances (Fig. 35) from B and A to the notch to be used, as $B4$ and $A4$, taking the average of five measurements.

(2) Attach the balance and wires to the sonometer, placing the fulcrum *F* at the proper notch. Place two bridges under both wires at some measured distance apart.

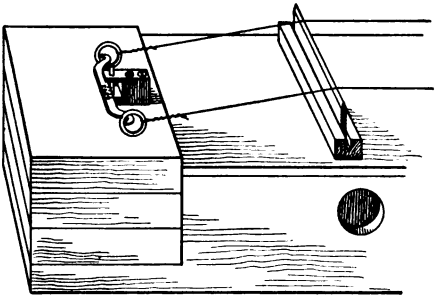


FIG. 36.

(3) With some measured length, of wire *A*, the wire with the greater tension, as 100 cm. (designated by L_A in the table), find a length l_B of wire *B* in unison with wire *A*. Use the method described in the last exercise.

Repeat with different lengths for L_A and find the ratio l_B to L_A in each case. Record the results as follows:

ARM *A*	ARM *B*	L_A					
		l_B					
		$\frac{l_B}{L_A}$					
		Average of $\frac{l_B}{L_A}$ = ...	$\frac{Arm\ A}{Arm\ B}$ = ...	$\sqrt{\frac{Arm\ A}{Arm\ B}}$ = ...			

Discussion. — By the corollary, page 82 (§ 246), the ratio of l_B to L_A = the ratio of the frequencies of the two strings when their lengths are equal, *i.e.* $\frac{l_B}{L_A} = \frac{\textit{frequency of } B}{\textit{frequency of } A}$.

By the law of parallel forces (§ 55) $\frac{Arm\ A}{Arm\ B} = \frac{\textit{tension on } B}{\textit{tension on } A}$.

Can you form a proportion showing the relation between the frequencies of the wires and their tensions? If so, state in words the meaning of the proportion.

CHAPTER V

LIGHT

EXERCISE 39

PHOTOMETRY

Purpose. — *To study the relation of candle power and of intensity of illumination to distance.*

Apparatus. — A Bunsen photometer, which consists of a disk of unsized paper with a grease spot at its center (Fig. 37). Two mirrors are usually placed, one on each side of the disk, so that both sides of it can be seen simultaneously. Two blocks, each capable of holding four candles. Some candles of the size called "sixes." An optical bench, consisting of two meter sticks fastened end to end on a board; or the exercise may be conducted by placing the photometer and candles on a long table. The photometer support and candle blocks should be notched so as to slide along the meter sticks. A darkened room.

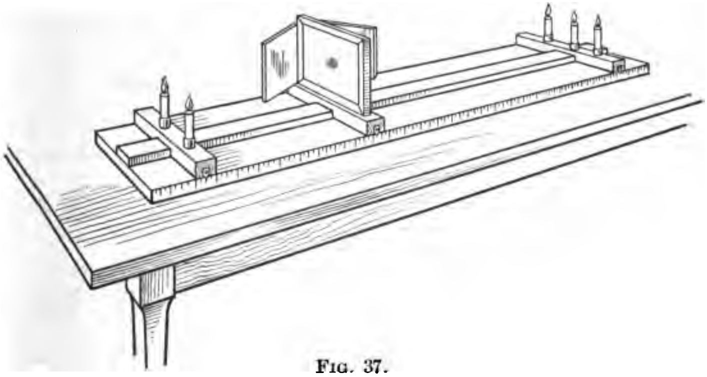


Fig. 37.

Procedure.—(1) Place the candles upon the bench with the photometer between them, having an unequal number of lighted candles on the two sides, as 3 and 2, or 4 and 3.

(2) Place the two sets of candles some exact distance apart, say 150 cm., recording the distance under *S* in the table.

(3) By moving the photometer to and fro, find such a position for it that its disk is illuminated equally on both sides. This will be the case when the center of the disk has the same, or nearly the same, appearance as the whole disk; or when its two sides appear alike in the two mirrors.

(4) When the correct position for the photometer is found, record the distances from the disk to the candle flames on each side.

Record the measurements for ten different trials, having the larger number of candles on the right during half of the trials and on the left for the remaining trials.

Record the data as follows:

$N =$ -------- $n =$ -------- $S =$ --------

Trials	d	D	Average of d squared = ---------
1			
2			Average of D squared = ---------
3			$\frac{d^2}{D^2} =$ --------
4			
5			$\frac{n}{N} =$ --------
6			
7			$\frac{i}{I} =$ ---------
8			
9			Error --------
10			
Average,			Per cent of error ---------

Let S = distance between two sets of candles.
Let n = smaller number of candles.
Let N = larger number of candles.
Let d = distance from n candles to photometer.
Let D = distance from N candles to photometer.
Let i = intensity of illumination of *one* of the N candles at distance D.
Let I = intensity of illumination of *one* of the n candles at distance d.

Discussion. — If the ratio $\frac{d^2}{D^2}$ agrees as far as its sure figures with the ratio $\frac{n}{N}$, you can form a proportion. State in words the meaning of this proportion, understanding that n and N stand for candle power.

Since i represents the intensity of illumination of *one* of the N candles, Ni = the intensity of illumination of N candles; likewise nI = the intensity of illumination of n candles. These two illuminations on the photometer were made equal in the experiment. Hence, $Ni = nI$. Dividing this equation by NI, we obtain $\frac{i}{I} = \frac{n}{N}$.

Place the numerical value of $\frac{i}{I}$ in decimal form in the table. This shows the relation of the intensity of illumination of one candle at distance d to that of one candle at distance D.

If the ratio $\frac{d^2}{D^2}$ agrees with that of $\frac{i}{I}$ in its sure figures, you can form another proportion from the two ratios. State in words the meaning of this proportion. If it is an inverse proportion, show why.

Great accuracy cannot be expected in this experiment chiefly because of the large variation in the size of the candle flames.

EXERCISE 40

INTENSITY OF A LAMP

Purpose. — *To measure the candle power of a lamp.*

Apparatus. — The same as for Exercise 39; a lamp whose candle power is to be measured.

Procedure. — (1) Substitute the lamp for one set of candles and light two candles on the other side of the photometer.

(2) Place the lamp and the candles some distance apart, as 100 or 150 cm., and then set the photometer as in Exercise 39, for equal illumination.

(3) Repeat the measurements several times either with the same distance from lamp to candles or with other distances.

(4) Calculate the candle power of the lamp by the first law derived in Exercise 39 (§ 264), in each case, and find the average of the several results.

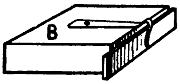
No. of Candles	Distance to Candles	Distance to Lamp	Candle Power of Lamp

EXERCISE 41

THE PLANE MIRROR

Purpose. — *To find the position of an image formed by a plane mirror and to compare the angle of incidence with the angle of reflection.*

Apparatus. — A mirror consisting of a strip of plate glass blackened on one side, fastened to a block by a spring or a rubber band (Fig. 38). A ruler. A protractor. A pair of dividers. A pin. A silvered mirror may be used, and in that case the back surface is the reflecting surface. With the blackened glass, the front surface is the reflecting surface.



Procedure. — (1) With a well-sharpened hard pencil draw a clear fine line *MN* (Fig. 38) across (not lengthwise) the center of a sheet of paper and label it "mirror." Place the mirror (block *B*) on the paper with the reflecting surface of the mirror exactly coincident with this line.

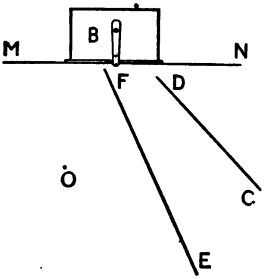


Fig. 38.

(2) Set a pin in front of and to one side of the mirror, placing it 8 or 10 cm. from the mirror, as at *O*.

(3) Place a straight-edged ruler on the paper so that its edge points exactly at the image of the pin seen in the mirror. To do this, place the eye on a level with the table and back from the end of the ruler 8 or 10 inches, and sight along the edge of the ruler at the image with one eye only. Be careful not to push the mirror off the line with the ruler.

(4) When the ruler is rightly placed, hold it firmly and draw a fine line along its edge as close to it as possible. In this way draw two such lines as *CD* and *EF*. After removing the ruler, test these lines by sighting along them to see if they point exactly toward the image.

(5) Remove the mirror and extend very carefully these lines until they meet. The point of intersection is the position of the image of *O*. Mark it *I*.

(6) From the point where *CD* meets *MN* draw a line to *O* and erect a normal to *MN* at that point.

(7) Place arrowheads on the lines to show the direction of the light from the pin to the eye, and mark the angle of incidence "*i*" and the angle of reflection "*r*."

(8) Measure these angles by a protractor and record the number of degrees of each angle in the angle itself.

(9) Draw a line from *O* to *I*.

Discussion. — In a real image the light actually passes through the image; in a virtual image it does not. Is this image real or virtual?

How does the line *MN* divide the line *OI*? Are these lines perpendicular to each other? What position does the image of a point in a plane mirror occupy?

How do the angles of incidence and reflection compare?

EXERCISE 42

INDEX OF REFRACTION OF WATER

Purpose. — *To determine the index of refraction of water.*

Apparatus. — A square battery jar, one side of which is covered with a paper having upon it a circle graduated in degrees. The paper within the circle is removed and its vertical and horizontal diameters are marked by lines on the glass, made by a glass cutter or by threads cemented across the circle (Fig. 39). The graduation should begin with zero at the ends of the vertical diameter and end with 90 at the extremities of

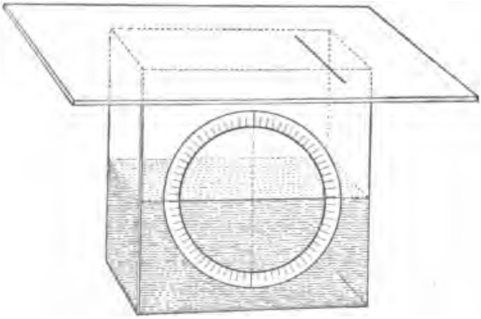


FIG. 39.

the horizontal diameter. A piece of cardboard considerably larger than the top of the jar, in which there is a slit about 2 mm. wide and 10 cm. long. A small mirror supported on a stand. The experiment can best be performed in a room somewhat darkened.

Procedure. — (1) Fill the jar with water exactly to the horizontal diameter. See that the surface of the water coincides with the diameter along its entire length.

(2) Place the cardboard over the top of the jar with the slit at right angles to the graduated circle; and, using direct sunlight or a beam of artificial light, send it through the slit by means of the mirror so that it will strike the water exactly at the center of the circle.

(3) Read the angle of incidence and the angle of refraction by the graduated circle. If the slit extends over the side of the jar a little, so that a part of the ribbon of light just grazes the graduated circle on the outside, the angle of incidence can be read more easily. Read at the center of the edge of the ribbon of light. The path of the light in the water will be more easily seen if a tiny amount of soap is added to it.

Record the data as follows: —

TRIAL	I	R	SINE OF I	SINE OF R	$\frac{\text{SINE OF } I}{\text{SINE OF } R}$
1 2 Etc.					
Average value found for the index..............................					
Accepted value (Table 12, Appendix).............					
Error................. Percentage of error...					

(4) Change the angle of incidence by a new adjustment of the positions of the jar, cardboard, and mirror, and repeat the measurements. Take measurements for several different incident angles.

Let I represent the angles of incidence, and R the angles of refraction.

For the values of the sines of angles, see Table 13 (Natural Sines and Tangents), Appendix.

TANGENT AND SINE OF AN ANGLE

These are trigonometrical terms. Let ABC (Fig. 40) be an angle. With B as a center, and any convenient radius, as BA, strike an arc cutting the two sides of the angle. From the point where the arc cuts one side, as A, extend a line tangent to the arc, until it intersects the line BC, as at D. The **ratio** of this line AD to the radius BA, or $\frac{AD}{BA}$, is the **tangent** of the angle ABC. Of course this ratio will be the same whatever the radius may be. It is obvious that the tangent of an angle of 45° is 1, for the line AD would then equal AB. For angles less than 45° it is less than 1, and for angles between 45° and 90° it is more than 1, being infinity for 90°.

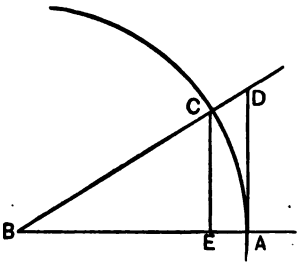


FIG. 40.

If a line be drawn from the point where the arc cuts one side, as C, perpendicular to the other side, as CE, the **ratio** of this line to the radius $\frac{CE}{AB}$ is the **sine** of the angle ABC. This ratio will obviously be the same whatever the radius may be, but no angle can have a sine greater than 1.

Tables can be found in the back part of any trigonometry giving the tangents and sines of any angle. (See also Table 13, Appendix.) These ratios are called the **natural** tangents and **natural** sines, to distinguish them from the logarithmic sines and tangents.

EXERCISE 43

REFRACTION

Purpose. — *To trace the path of a ray of light through a block of plate glass with parallel edges and to measure the index of refraction of the glass.*

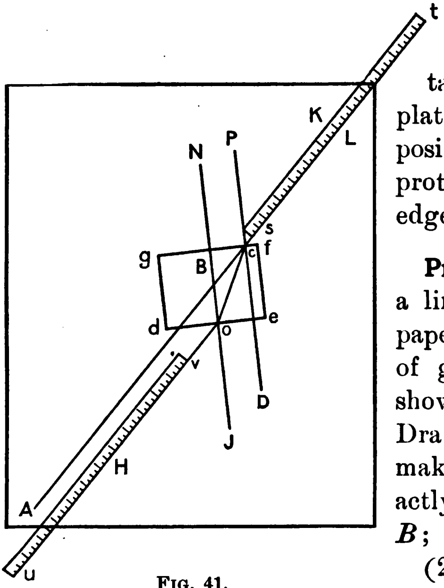


FIG. 41.

Apparatus. — A rectangular block of thick plate glass having its opposite edges parallel. A protractor. Two straight-edged rulers.

Procedure. — (1) Draw a line *AL* on a sheet of paper and place the block of glass *B* upon it as shown in Figure 41. Draw the lines *de* and *fg* making them coincide exactly with the edges of *B*; also draw *ef* and *dg*.

(2) Place one ruler at *K* so that its edge exactly coincides with line *AL*.

(3) Place the other ruler at *H* so that, as you sight

along its edge *uv* through the glass, *uv* and *st* shall seem to be in one straight line. When it is correctly placed, hold it firmly and draw the line *uv*.

(4) Remove the glass and extend *uv* to the line *de*, marking the intersection *o*. Draw *oc*, also *PD* perpendicular to *fg* at *c* and *NJ* perpendicular to *de* at *o*.

(5) Place arrowheads on the path of the light from *L* to *c* to *o* to the eye. Mark the angles of incidence and refraction about the point *c* by arcs and the letters *I* and *R*, and about the point *o* by arcs and *I'* and *R'*.

(6) Measure these angles by a protractor. Find the sines of these angles in Table 13, Appendix, and calculate the index of refraction, air to glass and glass to air. As an alternative, circles may be drawn about the points *c* and *o* as centers and the sines constructed and measured (§ 269).

Record results as follows:

	ANGLE OF INCIDENCE *I*	ANGLE OF REFRACTION *R*	SINE OF *I*	SINE OF *R*	INDEX
At *c*					
At *o*					
At *c*					
At *o*					
At *c*					
At *o*					
At *c*					
At *o*					

Discussion. — Show what law of refraction is illustrated at *c* and what one at *o* (§ 268).

How does the path of the light after passing through the glass compare with its direction before entering the glass?

How does the index of refraction air to glass compare with that of glass to air?

EXERCISE 44

ANGLE OF A PRISM

Purpose. — *To measure the refracting angle of a prism.*

Apparatus. — A prism whose angle is to be measured. A protractor. A straight-edged ruler.

Procedure. — (1) Draw on a sheet of paper two parallel lines *BE* and *DF* (Fig. 42) about 1 cm. apart and stand the prism on end with the refracting edge midway between the two lines as at *A*.

(2) The line *BE* may be seen reflected in the face of the prism *AR*; and *DF* in *AK*. Find the lines of reflection *BS* and *DT* by sighting along the edge of a ruler as in Exercise 41. If a piece of black cardboard is placed on the opposite side of the prism while you are sighting, the reflection will be more easily seen.

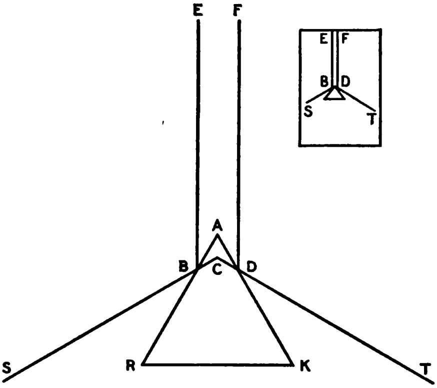


Fig. 42.

(3) Remove the prism, extend the lines *BS* and *DT* till they meet at *C*, and measure the angle *SCT* by a protractor.

Discussion. — The angle of the prism *A* equals one half of the angle *SCT*. The proof is as follows: From the law of reflection we can prove the angles *SBR* and *ABE* equal. Angle *SBR* = angle *ABC*, hence *ABE* = *ABC*. Likewise, *ADF* = *ADC*. Hence *AB* bisects the angle *CBE*; and *AD*, the angle *CDF*. By geometry, *RAK* = *ABE* + *ADF*; to prove this extend *RA* to the line *DF*.

Likewise, $SCT = CBE + CDF$. But ABE is half CBE and ADF half CDF, therefore RAK is one half of SCT.

Record the values of SCT and RAK in two columns and find the average value of RAK.

EXERCISE 45

REFRACTION BY A PRISM

Purpose. — *To trace the path of light through a prism; to measure the angle of deviation produced by a prism; and from it and the value of the refracting angle measured in the last exercise to calculate the index of refraction of the glass of the prism* (§ 276).

Apparatus. — A prism whose refracting angle A (Fig. 43) is known. A protractor. A straight-edged ruler.

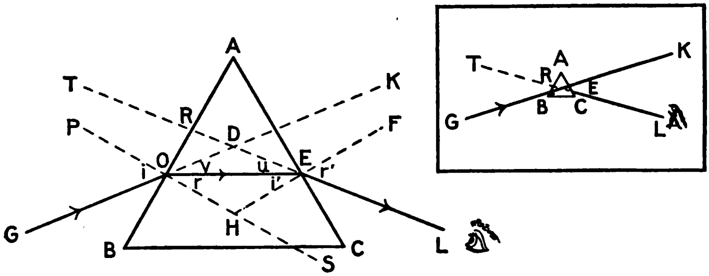


FIG. 43.

Procedure. — (1) Draw a diagonal line GK across a sheet of paper and set the prism on end on this line with angle A above it as shown in the Figure.

(2) Placing the eye on a level with the table and looking through the prism in the direction LE, the observer will seem to see the line OG at RT.

(3) The prism must now be set for the angle of least deviation (§ 278). This is the most difficult part of the experiment.

By turning the prism to and fro about A as an axis, the point T may be made to move either away from or toward G. When it is moving toward G the angle of deviation is decreasing. By trial make it as small as possible.

(4) After setting the prism for least deviation, place a ruler by sighting along it as in Exercise 43, so that its edge and the line OG seem to be in one straight line. Then hold the ruler firmly and draw the line LE. Another person can at the same time sight along the line GO at the ruler. Remove the ruler and test the line by sighting along it. LE and OG should seem to be one straight line.

A pin placed at G may assist you in seeing the line through the prism. Note the colors of the pin.

(5) Draw an outline around the base of the prism; then remove the prism and extend LE to T and draw OE. $GOEL$ is the path of the light from G to the eye.

(6) The angle KDL, represented by D in the table and in the Discussion, is the angle of deviation for the prism. Measure it by a protractor. Repeat the experiment and find the average of several measurements of the angle D.

(7) Draw the lines PS and FH perpendicular respectively to AB and AC.

Record the results as follows:

Trials	Angle D	
1		$D + A =$
2		$\frac{1}{2}(D + A) =$
Etc.		$A =$
		$\frac{1}{2}A =$
		$\text{Sin}\,\frac{1}{2}(D + A) =$
		$\text{Sin}\,\frac{1}{2}A =$
Average of D............		Index =

Discussion. — State clearly how the light is bent on entering the prism and on leaving the prism, also designate the two angles of incidence and the two angles of refraction.

To determine the index of refraction we must know the size of the incident angle i and of the refraction angle r. These can be calculated from the angles A and D which have been measured. The proof is as follows:

When the prism is set for the angle of least deviation, $\angle i = \angle r'$, $\angle i' = \angle r$, and $\angle v = \angle u$. By geometry, $\angle FHS = \angle A$ because the sides of one are respectively perpendicular to the sides of the other; also $\angle FHS = i' + r$, $\therefore \angle A = i' + r$. Since $i' = r$, $A = 2r$. Therefore,

$$r = \tfrac{1}{2} A. \qquad (1)$$

Since $\angle D = v + u$ and $v = u$, $v = \frac{1}{2} D$. $\angle i = v + r$. Substituting $\frac{1}{2} D$ for v and $\frac{1}{2} A$ for r in this equation, we have $\angle i = \frac{1}{2} D + \frac{1}{2} A$, or

$$i = \tfrac{1}{2}(D + A). \qquad (2)$$

Since the index of refraction = sine of the angle of incidence divided by the sine of the angle of refraction,

$$\text{Index of refraction} = \frac{\sin \frac{1}{2}(D + A)}{\sin \frac{1}{2} A}$$

The sines of these angles can be found in Table 13, Appendix, and the index of refraction of the glass of the prism calculated from them.

EXERCISE 46

THE CONCAVE MIRROR

Purpose. — *To measure the focal length of a concave mirror and to study images formed by a concave mirror.*

Apparatus. — An optical bench consisting of a meter stick fastened upon a board. A simple microscope, such as a linen tester, upon a block *N* (Fig. 44). A concave mirror fastened to a block *M*. A small piece of cardboard upon which fine lines or arrow heads are drawn, fastened to a block *O*. A pin or a needle fastened to block *N* as shown in the Figure.

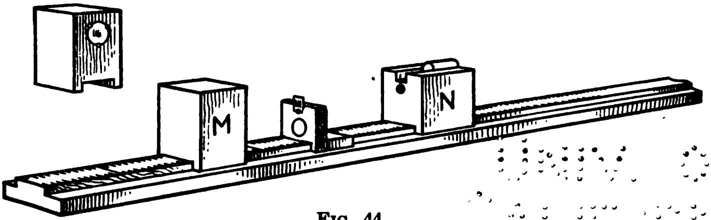


FIG. 44.

The fine lines on *O* constitute the object whose image is to be formed by the mirror. The microscope is used not because it magnifies but to locate the image with exactness. It does this because anything to be seen distinctly by it has to be at a definite place. If both needle and image are seen distinctly at the same time, they are both in the same plane.

Procedure. — (1) Take the block *N* in the hand and holding it close to the eye move the microscope back and forth until a position is found for it which gives a very distinct enlarged image of the needle. Keep the microscope in this position during the experiment. Anything else, such as an image of the lines, can be seen distinctly through the microscope only when it is in the plane of the needle ; hence, if you measure to the needle, you also measure to the image.

(2) Place the blocks on the bench as shown in the figure, making the *image distance v*, which is the distance from mirror to needle or from *M* to *N*, exactly 30 cm.

(3) Place block *O* very near the mirror and move it

slowly backward until you can see a distinct image of the lines through the microscope. In doing this keep the eye as near the microscope as possible. The image of the lines is now in the plane of the needle.

(4) When the correct position for *O* is found, measure the *object distance u*, or the distance from mirror to the object, *i.e.* from *M* to *O*.

(5) Again, make the image distance *v* exactly 28 cm., then 26 cm., etc., and find a position for *O* in each case as before.

(6) Finally remove block *O*, and, moving block *N* carefully back and forth, find a position for it in which an inverted image of the needle can be seen as large as the needle itself. The needle is now the object. Record both object distance and image distance under *u* and *v*.

If you have difficulty in seeing the images, let the instructor remove the microscope and adjust the mirror or card by placing the eye in line with them and about 10 inches back of the needle.

Record the results as follows:

u	v	$u+v$	$u \times v$	f

Discussion. — The focal length f is found by the formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$, which can be reduced to the more convenient form, $f=\frac{u \times v}{u+v}$ (§ 317). What positions (§ 316, Fig. 181) do image and object occupy in all trials but the last? In the last? What cases (§ 316) are illustrated? Describe the image completely for each trial.

EXERCISE 47

THE FOCAL LENGTH OF A LENS

Purpose. — *To measure the focal length of a convex lens.*

A. By Direct Sunlight

Apparatus. — An optical bench 1 m. long. A small convex lens. A small screen of white cardboard or ground glass. The screen and lens should be supported on blocks arranged to slide along the meter stick of the optical bench.

Procedure. — (1) Place the lens and screen upon the optical bench, having the plane of the screen normal to the meter stick, and the axis of the lens parallel to it.

(2) Place the apparatus in a beam of sunlight so that the rays of light shall be parallel to the meter stick, and, passing through the lens, shall be received on the screen.

(3) Move the screen back and forth until a position is found for it in which a small well-defined image of the sun is formed upon it.

(4) Measure the distance from the lens to the screen. Repeat the operation several times, and take the average of the several measurements as the focal length of the lens.

This distance is the focal length of the lens because the sun's rays are parallel (§ 321).

B. By a Distant Object

Apparatus. — The same as for the preceding experiment.

Procedure. — (1) Draw down the window shades, leaving a narrow opening at the bottom, and support the optical bench so that it points through this opening at some distant object.

(2) Place the lens upon the bench and back of it the cardboard screen, and then adjust the distance between lens and screen so that a distinct image of the distant object is formed upon it.

The more the light is excluded from the room, except that going through the lens, the better the image will be.

(3) Measure the distance from the lens to the image or screen and record it as the focal length of the lens.

(4) Remove the cardboard screen and put in its place the microscope used in Exercise 46. Locate the image formed by the lens by means of the microscope just as you did in that exercise.

(5) Measure the distance from the lens to the needle and record it as the focal length of the lens.

Record the results as follows:

Position of Lens	Position of Image	Focal Length

Discussion. — Part *B*, when the cardboard screen is used, illustrates the eye and the camera.

The microscope and the lens form a crude astronomical telescope, the lens forming the objective and the microscope the eyepiece of the telescope (§ 337).

Theoretically in Part *B* the image is between the principal focus of the lens and its secondary focus (§§ 323, 326), and the distance measured is greater than the focal length; but practically it is at the principal focus. This is true because the angle between rays coming from each point in the distant object and passing through the lens is so small that they are practically parallel; hence they meet in plane of the principal focus and form the image there.

EXERCISE 48

THE FOCAL LENGTH OF A CONVEX LENS

Purpose. — *To measure the focal length of a convex lens, locating the image by parallax.*

Apparatus. — Same as that used in paragraph 4 of Exercise 47, except that the microscope is removed from its supporting block.

Procedure. — (1) Support the apparatus so that as you sight past the needle through the lens the image of some distant object can be seen. The needle should be between the eye and the lens and about 25 cm. from the eye.

(2) Move the lens along the meter stick until the image it forms of the distant object coincides with the needle. To find this position, move the head to and fro from side to side. If the image is farther from the eye than the needle is, it will appear, *relatively to the needle*, to move in the same direction as the eye moves. If the image is nearer the eye than the needle is, it will appear to move, *relatively to the needle*, in an opposite direction to that of the eye. In this case move the lens away from the eye; in the first case the lens should be moved toward the eye. When the needle and the image coincide, there will be no motion of the two with respect to each other on moving the eye.

(3) Measure the distance from the lens to the needle, taking the average of several trials for the focal length of the lens. Record the data as in the last exercise:

POSITION OF LENS	POSITION OF IMAGE	FOCAL LENGTH

EXERCISE 49

FOCAL LENGTH OF A LENS. IMAGES

Purpose. — *To determine the focal length of a convex lens by conjugate foci and to study images formed by the lens.*

Apparatus. — An optical bench. A cardboard screen. A lens. A gas light. A sheet-iron cylinder having a T cut in its side. The room should be darkened somewhat.

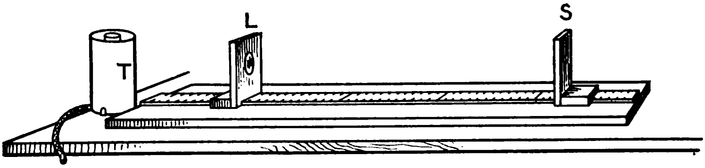


Fig. 45.

Procedure. — (1) Set up the apparatus as shown in Figure 45, placing the gas light within the cylinder on a level with the T and the end of the meter stick on the bench against the cylinder below the T.

(2) Make the distance from the T to the screen S, say, 100 cm. (this distance must be more than four times the focal length of the lens), and move the lens back and forth near the T until a position is found for it that gives a large distinct image of the T on the screen.

(3) Measure u, the object distance, *i.e.* from the T to the lens; and v, the image distance, *i.e.* from the lens to the screen. Measure by means of a pair of dividers H the height of the T and h the height of the image.

(4) Calculate f, the focal length of the lens, by the formula $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ (§ 327). See if you can form a proportion with the values obtained for u, v, H, and h. If so, what does it mean?

(5) Note what positions object and image occupy with respect to the focus, the secondary focus, and the lens (§§ 323, 326). Describe the image completely.

(6) Move the lens away from the T toward *S* until a small distinct image of it is formed, and repeat the measurements, etc., of (3), (4), and (5).

(7) Place *S* in a new position and repeat the experiment.

Record the results as follows:

u	v	H	h	f	$\frac{u}{v}$	$\frac{H}{h}$

Average value for f --.
Position of object in trial 1, ------------; in trial 2, ------------.
Position of image in trial 1, ------------; in trial 2, ------------.

State these positions by means of the points of reference (§ 323).

Trial 1 illustrates how pictures are projected by the magic lantern.

EXERCISE 50

WAVE LENGTH OF LIGHT

Purpose. — *To measure the wave length of sodium light.*

Apparatus. — A photographic copy of a diffraction grating having a known number of lines per centimeter (about 3000 lines per inch or 1181 per centimeter). A source of sodium light consisting of a Bunsen burner having around its top a piece of asbestos paper which has been soaked in a saturated solution of sodium nitrate. A piece of sheet iron having in it a slit nearly a millimeter wide and 2 or 3 cm. long. A meter stick. The room must be somewhat darkened.

Procedure. — (1) Place the sheet iron in front of the burner with the slit *S* vertical and on a level with the flame (Fig. 46). Support a meter stick, *MT*, by a clamp in a horizontal position in front of the slit and just below it. Support the grating at *G* in a line which is perpendicular to the meter stick and which passes through the slit and the flame.

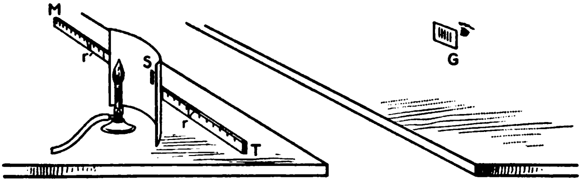


FIG. 46.

(2) Fix the distance from the grating to the meter stick exactly at some definite value, as 300 cm. Call this distance *D*.

(3) When the observer looks through the grating at the slit, he will see two images of it, one on the right of it and one on the left of it. Let a second person move the paper markers *r* and *r'* until their edges mark the exact positions of these images as seen by the one looking through the grating. The distance from *r* to *r'* divided by 2 is the distance from slit to image. Call it *d*.

Possibly two other images of the slit more distant from the slit may be seen; if the distance between them can be measured, one fourth of it will give the distance *d*.

(4) Let the observers exchange places and repeat the work.

(5) Change the distance *D* to 350 or 400 cm. and repeat the work.

Record the results as follows:

<table>
<tr><td colspan="5">No. of lines per cm. on grating = ---------- = <i>n</i></td></tr>
<tr><td><i>D</i></td><td>Position of <i>r</i></td><td>Position of <i>r</i>′</td><td><i>d</i></td><td>Wave Length</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Discussion.—(§§ 301, 302, 303.) If n represents the number of lines per centimeter on the grating, then $\frac{1}{n}$ is called the *grating constant;* it is the width of one space and one line on the grating. Let k represent this constant.

We now have three known quantities, k, d, and D.

$$\text{Wave length} = \frac{d \times k}{D}, \text{ or } \frac{d}{D \times n}, \text{ since } k = \frac{1}{n}.$$

The proof is as follows: Let GG (Fig. 47) represent a horizontal section of the grating, the short lines representing the thickness of the lines on the grating and the spaces the transparent spaces between them. Of course the actual dimensions are enormously exaggerated in Figure 47. ab, the width of one space and one line, is the grating constant k.

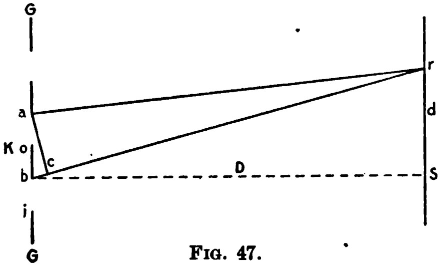


FIG. 47.

Let us suppose the light to go through the grating GG from the left toward s. Light in passing through a space is diffracted or spread out so that the light passing through ao interferes with that passing through bi. When the path from the space *bi* to *r* is exactly one whole wave length longer than that from *ao* to *r*, the two pencils of light meet in the same phase and intensify each other, forming the first diffraction image of the slit. As the distance *sr* increases, the difference between *ar* and *br* increases; and when it becomes exactly two whole wave lengths, the second diffraction image of *s* is formed. In the same manner images of the first order, second order, etc., are formed on the other side of *s*. In reality, in this experiment the images of the slit are formed on the retina of the eye and those seen on the ruler at *r* and *r′* are virtual, being projected on the ruler by the eye. The slit itself is seen at *s*.

Let *r* be the position of the first image of the slit, then the path *br* is just one wave length longer than the path *ar*. Since the space *ab* is exceedingly minute the lines *ar* and *br* are practically parallel. Make *cr* equal to *ar* and draw *ac*. *bc* is the wave length sought. $ab = k$, $bs = D$, and $sr = d$. The triangle *acb* is a right triangle and is similar to *bsr* and $\frac{bc}{ab} = \frac{sr}{br}$, or $bc = \frac{d \times k}{br}$. Without serious error we may substitute *bs* or *D* for *br* and we then have the formula given above for the wave length.

CHAPTER VI

HEAT

EXERCISE 51

TESTING A THERMOMETER

Purpose. — *To test the freezing point and the boiling point of a thermometer* (§ 343).

Apparatus. — A mercury thermometer. A cup of about 1 l. capacity. A Florence flask of about 1 l. capacity, or, better, a copper or tin dish like that shown in Figure 48 or "Apparatus A" of the Harvard list. If a flask is used, the heat rising from the flame about the sides of the flask may give rise to a large error. The flask should be set in a large square of asbestos paper. A barometer. An iron tripod or retort stand. A Bunsen burner. Some clean ice or snow.

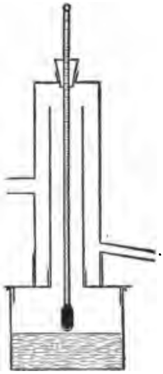


FIG. 48.

A. TO TEST THE ACCURACY OF THE FREEZING POINT MARK

Procedure. — (1) Suspend the thermometer in the cup by a clamp so that its freezing point mark shall be about on a level with the edge of the cup.

(2) Pack about the bulb of the thermometer and its stem, as far up as the freezing point mark, fine ice chips or snow.

(3) Allow it to stand several minutes until assured that the mercury has become stationary. Then read the position of the mercury, estimating the tenths of a degree.

Read it several times. It is not necessary to allow the water to run out of the cup as fast as the ice melts, as is often done. If plenty of ice is present, better results will be obtained by surrounding the thermometer with water. (Preston's Theory of Heat, p. 106.)

N.B. — In this and all other experiments in which a thermometer is used, it is very important in taking the reading that the *line of sight* shall be perpendicular to the thermometer. In the following experiments in Heat very much depends upon the accuracy with which the readings of the thermometer are taken.

B. To Test the Boiling Point Mark

Procedure. — (1) Fill the flask or basin about one third full of water, and place it over the flame so that the water shall boil vigorously. Suspend the thermometer so that its bulb shall be 2 or 3 cm. above the boiling water. The stem should be surrounded by the neck of the flask as far up as the boiling point mark.

(2) When assured by several readings that the mercury has become stationary, record the position of the mercury.

(3) Read the barometer and compute the true boiling point of water for the given pressure by allowing 0.37° C. per centimeter of variation from a barometer reading of 76 cm., or 0.937° C. per inch of variation from 29.92 in. Subtract this correction from 100° when the pressure is below 76 cm. or 29.92 in.; add it when it is above. The barometer reading should be corrected for temperature before applying this rule. (See Table 14, Appendix.)

Record the results as follows:

Thermometer No.-------------------------------
Graduation of stem extends from----------to---------
Observed freezing point----------- Error---------
Barometer ---------------------------------------
Computed boiling point-----------------------------
Observed boiling point------------ Error.---------

If the observed freezing point is below the mark, or the observed boiling point below the computed boiling point, call the correction *positive;* if above, call it *negative.* The correction is always added algebraically to an observed reading to obtain the true temperature.

C. To Plot a Curve by which the Correction for any Observed Temperature may be Found (Fig. 49).

Lay off a scale of degrees from 0° to 100° along a heavy vertical line on coördinate paper ruled in millimeters. Let distances to the right of this line represent positive errors and distances on the left, negative. Let one small square represent an error of 0.1°.

Opposite the observed freezing point lay off the error found, and opposite the observed boiling point lay off the error obtained. Then connect these two points by a fine straight line.

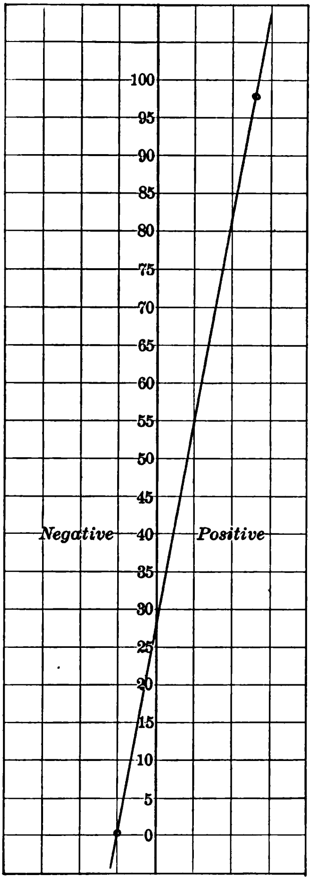


Fig. 49.

For example, suppose the observed freezing point was 0.5° above the mark, the error being −0.5°; and suppose the computed or true boiling point was 99.3° and the observed boiling point 98.0°, the error being +1.3°. Then 5 small squares are laid off on the left of 0.5° on the scale and 13 squares to the right of 98° on the scale and a line drawn as shown in Figure 49.

To illustrate the use of this curve, let us suppose a temperature of 55° was observed. By referring to the curve the error at that temperature is seen to be positive 0.5°. Hence the true temperature is 55.5°.

EXERCISE 52

COEFFICIENT OF LINEAR EXPANSION

Purpose. — *To measure the coefficient of linear expansion of brass.*

Apparatus. — A brass tube *TT* (Fig. 50), resting in a groove in block *C*, is fastened firmly to the table by an iron clamp. The tube presses upon a roller at *B*, the roller resting on a piece of ground glass fastened to the block *D*, which is also clamped to the table. A wire pointer *P* is soldered to the end of the roller and is counterbalanced by a weight at one end. A pin extends through the tube at *A* and is held firmly against the block *C* by a strip of brass not shown in the figure. Rubber tubes *K* and *L* are attached to the ends of the tube *TT*. A mirror scale is placed at *S*.

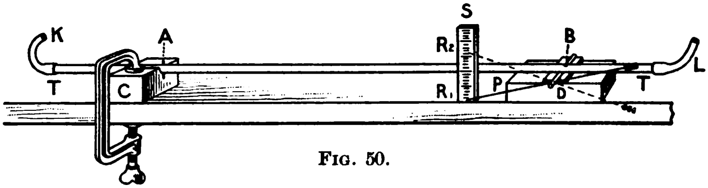


FIG. 50.

When the tube is heated by passing steam through it, it expands toward the right and turns the roller over a little way, moving the pointer over the scale *RR*.

Procedure. — (1) Remove the roller from its place and measure its diameter by a micrometer screw. Also measure the length of the pointer from its tip to the roller, adding the *radius* of the roller; call this length l.

(2) Place the roller under the tube again, with the pointer in the position shown in Figure 50, and measure the length of the tube from point A to point B, just above the middle of the roller. There should be a file mark at B to fix the position of the roller.

(3) Attach K to the water faucet and allow cold water to run through it for a while. The water escaping through L is caught in a vessel standing in a sink. Take the temperature of this water, estimating tenths of a degree. This will be the temperature of the brass tube.

(4) Read the position of the tip of the pointer on the scale S. This should be done at once after taking the temperature of the cold water. Let this be R_1.

(5) Disconnect the tube K from the faucet, blow through it to expel the water, and then attach it to a boiler so as to send steam through it. After the steam issues from L a short time, read again the position of the tip of the pointer on S. Let this be R_2.

(6) Take the temperature of the steam as in Exercise 51, B, or compute the boiling point from the barometer reading. This will be the temperature of the tube with the steam passing through it.

Record the results as follows:

Length of Pointer, l = --------- Diameter of Roller, d = ---------
Length of Tube, L = --------- $d \div l$ = ---------

TEMPERATURES			POINTER READINGS			EXPANSION	EXPANSION PER DEGREE	COEFFICIENT OF EXPANSION
With Cold Water	With Steam	Change	R_1	R_2	$R_2 - R_1 = R$			

Discussion. — If the 6 cm. mark of a ruler is placed on top of a pencil (Fig. 51) and is then rolled along toward the right until the pencil has rolled 1 cm., or from A to B, the 5 cm. mark will then be at the top of the pencil and the 6 cm. mark will be above C, or 2 cm. from A; the ruler, however, will have traversed an arc on the pencil 1 cm. long. This shows that the ruler travels a distance twice the length of the arc through which the pencil turns on its own axis.

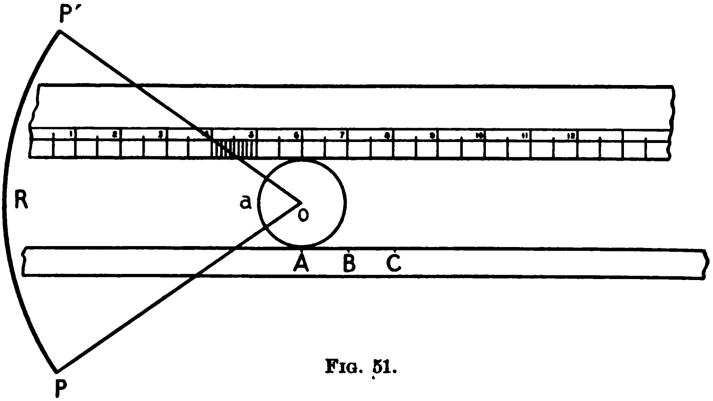


FIG. 51.

If a pointer oP is attached to the end of the pencil, the arc a traversed by a point on the surface of the pencil is to the arc R traversed by the tip of the pointer as the radius of the pencil r is to the length of the pointer l; $a : R = r : l$. Hence, $a = Rr \div l$. But the ruler moves twice as far as this, or $2\,Rr \div l = Rd \div l$.

Applying this to the apparatus, *the expansion of the tube = the distance the pointer moves on the scale × diameter of roller ÷ length of the pointer.*

The expansion divided by the change of temperature gives the expansion per degree; this divided by the length of the tube gives the coefficient of expansion (§ 351).

EXERCISE 53

EXPANSION OF AIR

Purpose. — *To measure the coefficient of expansion of air under constant pressure.*

Apparatus. — A piece of barometer tubing (Fig. 52) having at the bottom a little sulphuric acid *s*, and at *M* a thread of mercury. Two brass bands *D′* and *D* encircle the tube. These bands can be moved up and down the tube by a wire handle *H*. The mercury incloses the air *AB* upon which you are to experiment, and the acid keeps this air dry. A battery jar. Another cylindrical jar somewhat deeper than the battery jar. A thermometer. Some ice. A stirrer *R*.

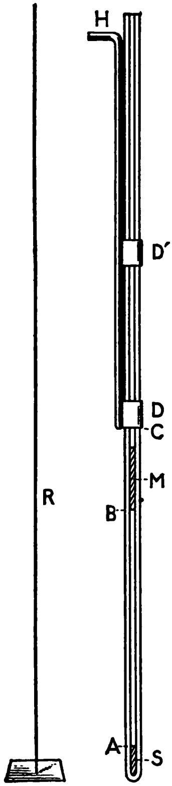


FIG. 52.

Caution. — Be very careful not to give the tube a jar or jerk, else the thread of mercury may be broken. Should it become separated, notify the instructor.

Procedure. — (1) Fill the battery jar with ice and water. Use rather large pieces of ice so that the ice will extend to the bottom of the jar. If the ice does not reach the bottom, the temperature of the water there will not be colder than about 4° C. We assume that the ice and water are at 0° C.

Place the tube in the ice water near the side of the jar so that you can see the mercury thread and after two or three minutes adjust the band *D* so that its lower edge *C* is even with the lower end of the mercury *B*. The water must be above *B*.

(2) Remove the tube and stand it in front of a meter stick or a mirror scale and measure the length from *A* to *C* by reading the positions of *A* and *C*.

This will be the volume of the air at 0° C., t_0.

(3) Place some water at about 50° C. (warmer water might break the jar) in the deep jar. Suspend the thermometer in the water by a wire which is bent over the edge of the jar. Now place the tube in the water near the thermometer. After a few moments adjust the band *D* as before and at the same time take the temperature of the water, t_1.

Since the water in such a jar very soon becomes several degrees colder at the bottom than at the top, another person should be constantly stirring the water while this adjustment is being made. Let the stirrer *R* be moved up and down at the back of the jar so as to avoid hitting the tube and the thermometer.

(4) Remove the tube from the jar and measure the air column as before.

Record the results as follows:

TRIALS	1	2	3
Lower temperature, t_0			
Top of air column at t_0			
Bottom of air column at t_0			
Volume of air at t_0			
Higher temperature, t_1			
Top of air column at t_1			
Bottom of air column at t_1			
Volume of air at t_1			
Amount of expansion			
Coefficient of expansion			
Average coefficient from three trials --------			

Discussion. — Subtracting the volume at 0° C., or t_0, from its volume at the higher temperature, t_1, gives the expansion of the air. Dividing this expansion by the change in temperature $(t_1 - t_0)$ gives the expansion for one degree, and dividing this result by the volume at 0° C. gives the coefficient, or the fraction of its volume at 0° C. which it expands per degree.

Reduce the average coefficient which you obtain to a common fraction having 1 for its numerator and compare it with $\frac{1}{273}$.

EXERCISE 54

SPECIFIC HEAT. WATER EQUIVALENT

Purpose. — *To find the specific heat of ~~a metal~~; also to determine the water equivalent of a calorimeter.*

Apparatus. — A platform balance. A set of weights. A thermometer. A basin of boiling water. A ~~cylinder~~ ~~made~~ of ~~the metal whose specific heat is to be determined and having~~ a ~~small hook or ring at the top.~~ ~~A barometer.~~ ~~A wire with a hook at one end.~~ A calorimeter ~~made of the same metal as the cylinder.~~

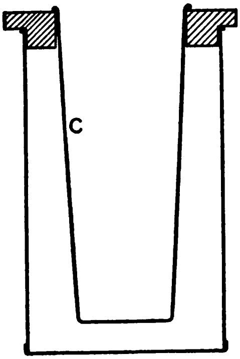


FIG. 53.

~~An~~ aluminum "lemonade shaker" is suitable for the calorimeter. Although not absolutely necessary, it is better to have an outer cup with a wooden ring in which the calorimeter can be supported as shown in Figure 53.

Procedure. — (1) Weigh the cylinder and then place it in a basin of water that is kept boiling. ~~Hook the wire into the ring on the cylinder so that the latter can be easily lifted from the water.~~

(2) Weigh the empty calorimeter (the inner cup).

(3) Fill the calorimeter about seven eighths full of water, using nearly enough to fill the calorimeter when the cylinder is immersed in it. This water should be ~~of about~~ above the ~~same~~ room temperature ~~as the air of the room, preferably~~ a degree or two ~~colder~~. Weigh the calorimeter and water.

(4) Take the temperature of the boiling water, covering as much of the stem of the thermometer as possible with the water; ~~or better, calculate the boiling point from the height of the barometer.~~

(5) Set the calorimeter near the boiling water. If it is not in an outer cup, shield it from the heat of the flame by standing a board between it and the flame and avoid handling the cup. Take the temperature of the water with great care.

(6) *Just as soon as possible after taking the temperature of the water*, transfer the cylinder from the boiling water to the calorimeter ~~by the wir~~e. ~~Remove the wire~~, stir the water around the cylinder thoroughly with the thermometer and read the temperature. Read it several times, stirring the water each time.

Caution. — Unless these two temperatures are read with great care, your results will be worthless. A thermometer cannot be read accurately if it is done hastily. Remember this in all the following exercises.

(a) *Only the top of the mercury thread should show above the water when the reading is taken.*

(b) *The line of sight must be perpendicular to the thermometer to avoid parallax, or you may easily make an error of half a degree or more.*

(c) *You must stir the water thoroughly.*

(d) *Estimate tenths of a degree carefully.*

(e) *Place the eye at least as close as 10 inches to the thermometer.*

Record the results as follows:

TRIALS	1	2	3
Mass of ~~cylinder~~ copper			
Mass of calorimeter + water			
Mass of calorimeter			
Mass of water taken			
Temperature of water after cylinder is added			
Temperature of water before cylinder is added			
Change of temperature of water and calorimeter			
Temperature of boiling water and cylinder			
Change of temperature of cylinder			
Specific heat obtained for copper			

Average = ---------

Accepted value------- Error------- Percentage of error------

Water equivalent of calorimeter No. =-------

Discussion. — Two principles are involved in the solution of this problem: First, that the amount of heat given off, or taken up, by a body equals *its mass × its specific heat × its change of temperature.* Second, that the amount of heat given off by the cylinder is transferred to and therefore equals that received by the water and calorimeter. Hence the two quantities can be equated ~~(§ 373)~~.

Heat lost by cylinder = heat gained by water + heat gained by cup. In solving this equation represent the unknown quantity, *i.e.* the specific heat of the metal, by *s*. ~~s appears in two quantities in the equation; transpose and unite them.~~

The *mass of the calorimeter* × s = the *thermal capacity* or *water equivalent* of the calorimeter. Having this quantity, you can in all exercises in which this calorimeter is used add it to the amount of water taken and then drop the calorimeter from further consideration in the solution of the problem.

EXERCISE 55

Purpose. — *To study the heat changes occurring during the solidification or freezing of a liquid* (§§ 389, 390).

Apparatus. — A basin of boiling water. A 6-inch test tube (a test tube "on foot" is most convenient). A thermometer. A watch. A basin of cold water. Some sodium thiosulphate, called hypo by the photographer.

Procedure. — (1) Fill the test tube about two thirds full with crystals of hypo, and melt them by holding the test tube in boiling water. When the crystals are all melted (be sure all are melted), the temperature should not be much if any above 70° C.

(2) Having notebook, watch, and all in readiness, support the tube with the thermometer standing in it in a basin of cold water at about 15° C. and at once begin to record the temperature and the time for every fifth degree while it is cooling. Let one pupil call off the temperatures while another notes and records the time. Do not disturb the liquid during the cooling.

(3) When it has cooled nearly to 20° C., drop in a crystal or two of hypo and then record the temperatures and time as rapidly as possible until rapid changes cease.

The liquid may be cooled in air instead of cold water, but the process is slow and the cooling should continue only for about 30°.

(4) Using the temperatures as ordinates and the times

from the beginning as abscissas plot a curve. Start at the origin with a temperature of 20°.

Record the results as follows, making the columns a page long:

TEMPERATURES	HOUR	MIN.	SEC.	TIME FROM BEGINNING

Discussion. — Write an explanation of the curve in your notebook. This experiment illustrates undercooling; that is, the cooling of a liquid below its freezing point without its freezing. What does it teach about solidification or freezing as to the production of heat?

NOTE. — The use of sodium thiosulphate for this experiment was suggested by Professor C. K. Studley of the California State Normal School.

EXERCISE 56

HEAT OF FUSION OF ICE

Purpose. — *To determine the heat of fusion of ice or the so-called latent heat of water ~~(§ 391)~~.*

Apparatus. — A calorimeter. A thermometer. A platform balance. Some clean ice. A cloth.

Procedure. — (1) Weigh the calorimeter, and ~~or if it is the same one used in Exercise 54,~~ record its weight and water equivalent in the tabular form.

(2) Prepare several lumps of clean ice varying in size from that of a walnut to that of a hen's egg.

(3) Fill the calorimeter about three fourths full of water at about 40° C. and then weigh the water and calorimeter.

(4) Place the calorimeter in its outer cup and then stirring thoroughly with the thermometer take its temperature accurately. It should not be much if any above 40° C.

(5) Immediately after reading the temperature, add lumps of ice to the water. Wipe each lump dry before dropping it in. Add the large lumps at first, then later, as the water cools, smaller lumps.

(6) Stir the water and ice constantly with the thermometer, meanwhile watching the temperature. Just as soon as the ice is all melted read the temperature again accurately. The temperature should be below 10° C. If it is not, add more ice.

(7) Weigh the calorimeter and the water it contains so that the amount of ice that has been added can be obtained.

Record the results as follows:

Trials	1	2	3
Mass of calorimeter			
Mass of calorimeter + water			
Mass of water taken			
Water equivalent of calorimeter			
Mass of calorimeter + water + ice			
Mass of ice added			
Temperature of water at first			
Temperature after ice is melted			
No. of degrees water and calorimeter are cooled			
No. of degrees the melted ice is warmed			
Heat of fusion of ice			

Average.........

Accepted value....... Error....... Percentage of error.......

Discussion. — The heat lost by the water and the calorimeter is used partly in melting the ice and partly in warming the ice water made from the ice. Add the water equivalent of the cup to the mass of water taken and find the heat lost by this mass of water. Find the heat used in warming the ice water and subtract it from the heat lost by the water; the remainder is the amount of heat used in melting the ice. This remainder divided by the number of grams of ice used will give the amount of heat necessary to melt 1 g. of ice or the heat of fusion of ice.

EXERCISE 57

HEAT OF VAPORIZATION OF WATER

Purpose. — *To determine the heat of vaporization of water or the so-called latent heat of steam* (§ 396).

Apparatus. — A calorimeter. A thermometer. A gas burner. A ~~boiler S (Fig. 54) to furnish~~ steam generator and trap ~~having a lamp chimney R attached fo~~r a "trap." Scales & weights. This serves to catch and hold the water that condenses from the steam in its passage from *S* to the calorimeter, so that steam and no water passes through the tube *T*. The chimney is supported in a notch of the board *A*.

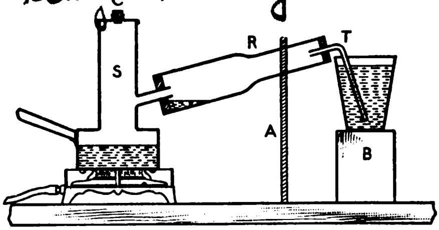


FIG. 54.

Procedure. — (1) Record the weight and water equivalent of the calorimeter.

(2) Fill the calorimeter about seven eighths full of cold water, say at about 10° C., and weigh it.

(3) Take the temperature of the water in the calorimeter very accurately.

(4) As soon as possible after taking this temperature

place the calorimeter in the position shown in Figure 54, by first removing the block *B* and then replacing it. Steam should be issuing vigorously from *T* before the calorimeter is put in position.

(5) Watch the rise of temperature in the calorimeter, and when it has risen to about 35° (it will take but a few moments), quickly remove the calorimeter.

Stir thoroughly and take the temperature accurately.

(6) Weigh the calorimeter and water to ascertain how much steam has been added.

(7) Find the temperature of the steam ~~either directly as in Exercise 51, *B*, or by calculating it from the barometer reading~~.

Record the results as follows:

TRIALS	1	2	3
Mass of calorimeter			
Mass of calorimeter + water			
Mass of water taken			
Water equivalent of calorimeter			
Mass of calorimeter + water + steam			
Mass of steam added			
Temperature of water and calorimeter at first			
Temperature of the same after addition of steam			
Temperature of steam			
No. of degrees water and calorimeter are warmed			
No. of degrees the condensed steam is cooled			
Heat of vaporization of water			
	Average -------		
Accepted value------- Error-------- Percentage of error--------			

Discussion. — The heat produced by the steam in condensing into water at the same temperature as the steam, and the heat given up by this same water in cooling, are both given to the cold water and the calorimeter. First find how much heat the water and calorimeter receive. If from this amount you subtract the amount of heat given to it by the condensed steam or hot water, the remainder will be the amount of heat produced by the steam in changing from steam to water. This remainder divided by the number of grams of steam added will give the amount of heat produced by one gram of steam in condensing to water, or the heat of vaporization of water.

EXERCISE 58

VAPOR TENSION

Purpose. — *To show that the vapor tension or pressure of a saturated vapor depends on its temperature; also to observe the vapor tension of a liquid at the boiling point of the liquid.*

Apparatus. — A U-shaped tube ~~(Fig. 55)~~ having its short arm closed. This tube contains some mercury and a small amount of alcohol in the closed end, ~~as shown in the Figure~~. There should be no air in the closed end of the tube. A similar tube containing a little water instead of alcohol. A thermometer. A test tube with a two-hole stopper containing a little alcohol. A cone-shaped flask ~~on a sand bath~~. A Bunsen burner.

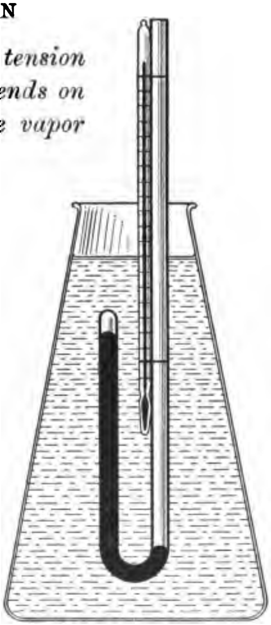


FIG. 55.

Procedure. — (1) Fill the flask nearly full of water and support the U-shaped tube containing alcohol in the flask so that its short arm is entirely covered by the water. Suspend the thermometer in the water beside the tube or bind it to the tube with rubber bands.

(2) Heat the water slowly and watch the alcohol. As soon as it vaporizes note carefully the movement of the mercury and also the temperature changes. When the mercury is at the same level in the two arms, the vapor tension of the alcohol vapor equals the atmospheric pressure. Note the temperature the instant this occurs. How does the vapor tension change as the temperature rises?

(3) Remove the tube from the flask. Support the thermometer in the test tube containing the alcohol by pushing it through one of the holes in the stopper. The thermometer should not quite touch the alcohol. Place this test tube in warm water, heating the latter until the alcohol boils. When the temperature reading has become constant, take the temperature at which the alcohol boils. The other hole in the stopper should be large enough to allow the vapor of the alcohol to escape freely.

(4) With the water in the flask about an inch deep, support the U-shaped tube containing water in the flask just above it. Boil the water in the flask. Watch the vaporization of the water in the tube and note at what point the mercury becomes stationary. If it does not become stationary, it is because air enters the flask and cools it. To prevent this, cover the flask loosely with a piece of paper through which a hole has been made for the tube. Note what happens to the vapor tension if this paper closes the flask so the steam cannot escape freely. Explain.

Record the results as follows:

Temperature at which vapor tension of alcohol equals the pressure of the atmosphere ______________
Temperature at which alcohol boils ______________
Difference ______________
Vapor tension of steam at the boiling point of water is ______________

Complete the following definition of the boiling point of a liquid: The boiling point of a liquid is the temperature at which the vapor tension of its vapor is ____________.

According to this definition ~~and Table 16, Appendix~~, at what temperature will water boil at the top of Mt. Blanc, where the barometer sometimes stands at 450 mm.? See table (tension of water vapor.

If by an air pump the pressure on water in a bell jar is reduced to 92 mm., at what temperature will the water boil?

EXERCISE 59

THE DEW-POINT

Purpose. — *To determine the dew-point and relative humidity of the atmosphere* ~~(§§ 401–403)~~.

Apparatus. — A nickel-plated cup or a metal cup with a bright and highly polished surface. A thermometer. Some snow or chopped ice. ~~A spoon~~.

Procedure. — (1) Fill the cup a little more than half full with water at about 20° C.

(2) Add gradually small quantities of snow or ice to the water, stirring it with the thermometer. Let each addition melt completely before adding more.

(3) Watch the outside of the cup for the first appearance of cloudiness or moisture upon it as the water cools. Read the temperature of the water when this occurs. Call this the "Temperature of appearance."

Carefully avoid breathing on the cup or placing the hands near its outside surface.

(4) Add now small quantities of warm water, stirring thoroughly and letting each addition produce its effect before adding more. Note the temperature of the water when the moisture on the outside begins to disappear. Call it "Temperature of disappearance."

The average of the temperatures of appearance and disappearance will be the *dew-point*.

(5) Take the temperature of the air of the room.

(6) Look up in Table ~~17, Appendix~~, the number of grams of water vapor required to saturate the air at the temperature of the room, also at the temperature of the dew-point. The latter quantity is the quantity of vapor actually present in the air of the room. To find the relative humidity, find the ratio of the vapor actually present to the quantity that could be present at the given temperature.

Record the results as follows:

TRIALS	1	2	3
Temperature of appearance			
Temperature of disappearance			
Average of the two, or dew-point			
Temperature of room			
Grams of water vapor per cubic meter at dew-point			
Grams of water vapor to saturate the air at temperature of room			
Relative humidity			

CHAPTER VII

MAGNETISM AND ELECTRICITY

EXERCISE 60

THE FIRST LAW OF MAGNETS

Purpose. — *To study the action of one magnet upon another* (§§ 440, 441, 451).

Apparatus. — Two darning needles. A bar magnet. A cork. Some sealing wax. A saucer filled with water.

Procedure. — (1) Magnetize the two needles by drawing the same pole of the bar magnet several times along the whole length of each, always in the same direction.

(2) Note which pole of the bar magnet is used and which end of the needle is last touched by it.

(3) Float one of the needles on a cork in the saucer of water. Mark the north-seeking pole with sealing wax or in some other convenient way. Repeat the operation with the other needle.

(4) Bring the north-seeking pole of the other needle near to the poles of the floating needle, and note the results. Try also the south-seeking pole. Then exchange the needles and repeat the operations.

Is the end of the needle last touched by the bar magnet the same in polarity as the pole of the bar magnet used, or opposite?

How do like poles affect each other? unlike poles?

(5) Test any upright mass of iron, such as a stove, the iron end of a desk, or a post, with a compass or a magnetized darning needle suspended by an untwisted thread,

first at the top, then at the bottom. Is it magnetized? If so, how are its poles located?

EXERCISE 61

EFFECT OF BREAKING A MAGNET

Purpose. — *To test the magnetism of the pieces of a magnet.*

Apparatus. — A magnet. A compass or a floating needle such as that used in the last exercise. A piece of watchspring about 10 cm. long.

Procedure. — (1) Magnetize the piece of watchspring and test and mark its poles.

(2) Break the spring into two pieces and test the ends of each piece for magnetism by the compass or the floating needle.

(3) Break these pieces and test the parts again as before. Continue this process of breaking and testing as long as you can.

(4) Lay the pieces down in their original order and note their arrangement as to their magnetic properties or poles.

Discussion. — Do you think this experiment supports the theory that the molecules of a magnetic substance are magnets and that in a magnet the like poles of the molecules point in the same direction?

EXERCISE 62

MAPPING A MAGNETIC FIELD BY A COMPASS

Purpose. — *To map the magnetic field of a bar magnet by means of a compass* (§§ 452, 453).

Apparatus. — A bar magnet. A large sheet of paper. A small compass.

Procedure. — (1) Place the magnet on the center of the sheet of paper with its north pole pointing north, and draw a line close to the magnet all about it, thus outlining the magnet upon the paper. Mark this outline with the letters *N* and *S*, corresponding to the poles of the magnet.

(2) Place the compass at the northeast corner of the magnet and then move it slowly away, moving the compass in the direction in which the needle points, and changing the direction of motion as the needle changes its direction. Continue this movement until the edge of the paper is reached, or until the compass returns to the magnet.

(3) Trace upon the paper with a pencil the path taken by the center of the compass needle.

(4) In like manner trace several more lines of force, starting about a half centimeter nearer the center of the magnet each time; also trace some lines, starting at the south pole of the magnet. Then in the same way map out the magnetic field on the west side of the magnet.

(5) Each line may be tested at any point after it is drawn by placing the compass directly over it. The direction of the line should agree with that of the compass.

Assuming that the direction of a line of force is the same as that in which the north-seeking pole of the compass needle points, test each line drawn and place several arrow heads at different points on the line indicating the direction of the line of force.

(6) Either fasten the paper in your notebook, or make a copy of the figure in the notebook.

State in your notebook whether lines of force enter or leave the magnet at its north pole. What do they do at the south pole?

It is the theory that all lines of force leaving a magnet return to it again. Does this seem to be true in this case?

EXERCISE 63

MAPPING A MAGNETIC FIELD BY IRON FILINGS

Purpose. — *To map magnetic fields of magnets by iron filings and to study permeability* (§ 454).

Apparatus. — Two bar magnets. A horseshoe magnet. A small piece of soft iron and an armature for the horseshoe magnet. A small muslin bag containing iron filings. A few pieces of thin boards.

Procedure. —

PART A

(1) Place a bar magnet upon the table and about it some boards of the same thickness as the magnet, and then spread over these a smooth sheet of paper.

(2) Sift from the muslin bag iron filings *evenly* and *thinly* over this paper, and then tap it gently with a pencil or jar the table with the fist.

(3) Make a drawing in your notebook of the figure formed.

PART B

(1) Place two bar magnets parallel to each other and about one third their length apart, their unlike poles being adjacent. Map out the field in the same manner as in Part A.

(2) Repeat the operation, placing like poles adjacent.

PART C, PERMEABILITY

(1) Map out as in the preceding exercise the magnetic field of a horseshoe magnet, first without any armature, then with an armature.

(2) Place the small piece of soft iron near, but not in contact with, the poles of the horseshoe magnet; or place

it between the unlike poles of two bar magnets, but not in contact with them, and map out the field as before. The piece of iron should be about as large as a silver quarter, and as thick as the magnets. It can be kept from sliding towards the magnets by small bits of wood.

Permanent copies of these figures can be obtained by placing a sheet of unsized paper, moistened with a solution of tannin, carefully over the figure formed by the iron filings. Press the paper down gently upon the filings by a blotter and then lift it off carefully, allowing the filings to cling to the paper. When dry, brush off the filings and fasten the copies so made in your notebook.

Beautiful prints of these fields may be made upon blue-print paper or upon photographic paper. To do this, place the magnets upon a drawing board and cover them with the sensitive paper. Then sift the iron filings upon the paper as before. This must be done in a light that will not affect the paper, then a proper exposure to light is made. For blue-print paper the board should be placed in direct sunlight for 10 or 15 minutes. The filings are then removed and the paper washed for a half hour.

EXERCISE 64

THE VOLTAIC CELL

Purpose. — *To study the essentials of a voltaic cell, that is, a so-called battery, and to learn about local action in a cell* (§§ 458–463).

Apparatus. — A tumbler about two-thirds full of sulphuric acid, H_2SO_4 (1 part acid to 15 or 20 parts of water). A strip of zinc and one of copper, also strips of other metals such as iron, lead, and aluminum. A rod of carbon. Two extra tumblers to place the metal strips in when not in use. A stand fitted with clamps to hold the metal strips in the acid (Fig. 56). A galvanoscope (Fig. 57), or better a tangent galvanometer (Fig. 58). A little mercury.

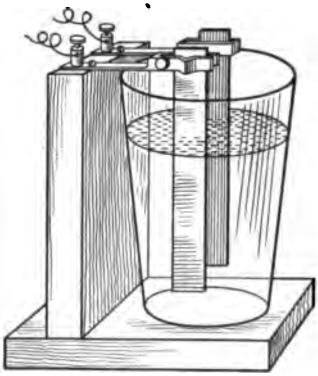


FIG. 56.

Procedure. — (1) Without using the clamps and stand, place the zinc strip in the acid alone and note what occurs on its surface. Do the same with the copper.

(2) Place both strips in the liquid and note what occurs on the surface of each; first, when they are not in contact; second, when touching under the liquid; third, when they touch outside the liquid; and fourth, when they are held in the clamps and are connected by wires. Note the effect on the copper of repeatedly making and breaking the connection between the plates.

Whatever apparent action you observe on the zinc is known as *local action.*

(When the galvanoscope is in use, it must be placed so that wires of its coil are north and south.)

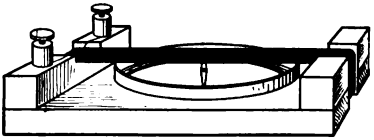


FIG. 57.

(3) Let the metallic connection between the plates be made by the wire of the galvanoscope or the galvanometer by joining to its binding posts the wires attached to the clamps. Note the action of the needle on completing the connection.

A wire that affects a magnetic needle near it, as this does, is said to have an electric current passing through it; and an arrangement of plates and a liquid such as you have constitutes a voltaic cell or battery.

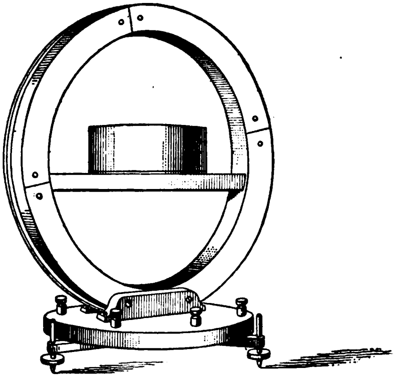


FIG. 58.

(4) Amalgamate the zinc by dipping the end of it wet with the acid in a little mercury. Spread the mercury over that part of the plate which enters the acid by a tooth brush.

(Keep the amalgamated zinc in a tumbler by itself when it is not in use, and do not allow it to touch the copper at any time, as the mercury will spread over it. This must be avoided.)

Repeat the work of the last three paragraphs, using the amalgamated zinc, but omitting that part where you are told to touch the plates under the liquid. What has the amalgamation prevented?

(5) Let some of the class try a rod of carbon with the zinc and see if it will make a cell; let others try iron and zinc; others lead and zinc, or any combination of two metals. Also let some try two copper plates, or any two like plates. The results should be reported and the whole class should record them.

(6) Turn the acid into a jar kept for the purpose, rinse out the tumbler, and rinse off the plates in running water.

Place a tablespoonful of common salt in the tumbler and fill it two thirds full of water. See if this with the copper and zinc plates will make a cell. Let some of the class use instead of the salt a small amount of potassium hydroxide.

Discussion. — We learn in chemistry that the gas produced in this experiment is hydrogen. If you should use this cell for a while, the zinc would be consumed, while the copper would apparently be unaffected. Hence, although much of the chemical action was apparently on the copper, it was really all on the zinc. That part of the chemical action on the zinc which liberated hydrogen on the zinc, called **local action**, contributes no current to the wire and is useless and wasteful. State in your book how it is prevented.

Write out fully in your book what you consider to be the essentials of a voltaic cell.

EXERCISE 65

POLARIZATION OF CELLS

Purpose. — *To study polarization of cells, its cause, and its remedy* (§ 464).

Apparatus. — A tangent galvanometer having a coil of 25 to 50 ohms resistance. A tumbler containing sulphuric acid and water. Some strips of copper. Two carbon rods. A strip of amalgamated zinc. Some nitric acid. The stand used in Exercise 64. A small porous cup. A glass spatula.

Procedure. — (1) Form a simple cell as in Exercise 64, using a dry, clean copper plate. If it has recently been used in a cell, it should be heated in a Bunsen flame, and polished with emery cloth. Join this cell to the long coil of the galvanometer. As soon as the needle becomes still record the number of degrees of deflection and then watch the needle for several minutes. Note whether the current becomes weaker, or stronger, or remains the same. The effect which you will probably observe is called **polarization** of the cell.

(2) After the galvanometer reading becomes constant, stir the acid about the copper plate with a glass spatula very vigorously so as to remove the hydrogen from it. What does the needle show about the current while you are stirring? What happens to the needle as soon as you stop stirring? Does the result seem to show that the hydrogen is the cause of the polarization?

(3) Short-circuit the cell by holding a strip of copper in contact with the copper and zinc plates. This will produce a greater quantity of hydrogen on the copper. Then, without disturbing any of the connections, take out the zinc plate and put a clean, dry, copper strip in its place, noting the action of the needle at the same time. You will see that the hydrogen on the other copper plate sends a current in the opposite direction.

This explains why hydrogen polarizes a cell. It tends to send a current backward through the cell.

(4) If time permits, repeat all of the above work, using a carbon rod in place of the copper.

(5) Fill a small porous cup with some of the solution from the tumbler and place the porous cup in the tumbler and the carbon rod within it. Place the zinc strip in the acid outside of the porous cup and then connect the cell as before to the galvanometer.

Allow the cell to polarize, then add 2 or 3 cc. of strong nitric acid to the porous cup. Watch the needle of the galvanometer for some time. Chemistry teaches us that the nitric acid will use up the hydrogen by furnishing oxygen to unite with it and form water. Does it prevent polarization?

Discussion. — All cells use some chemical agent to prevent polarization by acting upon the hydrogen or other element appearing at the positive plate.

EXERCISE 66

DEFLECTION

Purpose. — *To study the action of an electric current upon a magnetic needle.*

Apparatus. — A dry cell or some other form of the voltaic cell. About 1.5 m. of insulated copper wire about No. 22, attached to one pole of the cell. Do not attach both ends of the wire to the cell, for then the cell will polarize and become useless. A compass or magnetic needle.

Procedure. — (1) Remember that the current always flows through the wire *toward the zinc* plate of the cell when the connection is made. Stretch the middle portion of the wire above the compass needle and parallel to it, so that the current will flow toward the south. Note the effect on the needle on closing the circuit by holding the free end of the wire in contact with the other pole. This action is called *deflection.* Record the deflection (not the number of degrees) simply as *east* or *west* according to the direction the north pole of the needle turns.

(2) Try the same with the current flowing from south to north above the needle.

(3) Note the effect when the wire is placed under the needle so that the current flows from north to south below the needle.

(4) Again, note the effect with the current flowing from south to north below the needle.

(5) Place the compass on the end of a book standing on end and stretch a portion of the wire in a vertical position near the north pole of the needle. Note the effect, first, when the current is flowing up, and then when the current is flowing down.

(6) Repeat the last operations at the south pole of the needle. Can you tell from the results of the above opera-

tions what the effect would be if the current were passed entirely around the needle in a north and south *vertical* plane?

(7) Pass the wire once around the needle in a north and south vertical plane, and note the effect when the current is flowing first in one direction and then in the other.

Study in this connection the tangent galvanometer.

Record the results as follows:

1. Current above the needle from north to south, deflection........
2. Current above the needle from south to north, deflection........
3. Current below the needle from north to south, deflection........
4. Current below the needle from south to north, deflection........
5. Current up past the north pole, deflection...................
6. Current down past the north pole, deflection..................
7. Current up past the south pole, deflection....................
8. Current down past the south pole, deflection..................
9. Current all around the needle, going north on top, deflection.....
10. Current all around the needle, going south on top, deflection.....

Discussion. — It is difficult to remember these deflections, hence a rule by which they can be easily determined is convenient. Place the wire in each of the eight positions given and grasp it with the right hand, the thumb being extended in the direction of the current. Compare in each case the deflection with the direction the fingers point on the side of the wire nearest the needle. (It is not necessary to complete the circuit each time, but the results in the table may be used.) Devise and write in your book a rule by which the deflection can be determined when the direction of the current is known, or the direction of the current determined from the deflection. Join your cell to the tangent galvanometer and see if you can apply your rule to it.

Would this experiment indicate that there is a magnetic field about a current of electricity?

It is evident that if the needle or magnet were fixed in its position and the coil arranged so as to turn easily, the coil would be turned so as to assume an angle with the magnet when the current is sent through it. Galvanometers consist essentially of a coil of wire and a magnet. In some instruments the magnet is the movable part and the coil is stationary, while in others the reverse is true. It would be well for the student now to make a study of galvanometers both by reading about them and by examining any available instruments.

EXERCISE 67

AN ELECTROMOTIVE SERIES

Purpose. — *To determine whether one metal is positive or negative with reference to another in a cell.*

Apparatus. — Same as for Exercise 64, and in addition plates of iron, lead, carbon, and aluminum.

Procedure. — (1) Taking one of these plates, as copper, form a cell with each of the others in turn, and by the galvanoscope determine in each case which is the positive and which is the negative plate.

(2) Continue the above process until as many different combinations as possible have been made with the five plates.

(3) Arrange the plates in a series such that if any two of them be taken to form a cell, the first in the series shall be the positive plate.

Record the data in a table as follows:

No.	Positive Plate	Negative Plate	Series
1			
2			
3			
etc.			

EXERCISE 68

ELECTROMAGNETS

Purpose. — *To study the construction of the electromagnet and to learn upon what its polarity depends* (§ 480).

Apparatus. — A dry cell or other source of electric current. Three or four meters of insulated copper wire about No. 26. A 4-inch test tube. A soft iron rod of a diameter that will slip into the test tube, the rod having a file mark at one end. A compass. Some iron filings.

Procedure. — (1) Wind the wire in a neat close spiral around the test tube and then connect the ends of the wire to the cell, thus sending an electric current through it. Test the coil of wire to see if it is a magnet by applying each end of it to the ends of the compass, also by applying the ends of it to iron filings. If it attracts the filings, break the circuit and note the result.

(2) Reverse the current in the wire by changing the connections at the cell, and record any change in the coil, testing it with the compass. The material of the tube has nothing to do with the effect observed. The tube may be of any material except iron, such as paper, wood, or brass.

(3) Place the iron rod within the tube and repeat the experiments. Record the effect of using the bar. The iron rod is called a *core.*

(4) Begin at the middle of the wire and wind half of it on one test tube and half on another. Wind it in such a way that the mouth of one tube shall be a north pole and the mouth of the other shall be a south pole, so that the tubes placed side by side practically form a horseshoe magnet.

Is it the way the wire is wound or the direction around the coil that determines the poles?

(5) Note the effect on the strength of the magnet of reducing the number of turns of wire in the coil.

(6) Grasp the coil in the right hand so that the fingers encircle it in the same direction as the current flows. Note toward which pole the thumb points and thus devise a rule by which the poles of an electromagnet can be determined when the direction of the current is known, or the direction of the current when the poles are known.

Let the student now examine and study an electric bell, telegraph sounder, relay, and other instruments of which an electromagnet forms a part.

THE TANGENT GALVANOMETER

THE LAW OF THE TANGENT GALVANOMETER

The law of the tangent galvanometer (Fig. 58) is that the *strength of the current is proportional to the tangent of the angle of deflection* (§ 489). For example, suppose that a current of 0.8 of an ampere, passed through a tangent galvanometer, produces a deflection of 31°, and that another current of unknown strength produces a deflection of 61°. By the above law the strength of the second current can be determined by comparing it with the first.

Let x equal the strength of the unknown current in amperes. Then

$$0.8 : x :: \tan 31° : \tan 61°.$$

From a table of tangents (Table 13, Appendix), it is found that the tangent of 31° is 0.601 and the tangent of 61° is 1.804; hence

$$0.8 : x :: 0.601 : 1.804.$$
$$x = 2.4 \text{ amperes.}$$

It is evident from the above illustration that it is necessary to know what deflection some known current will produce in any particular galvanometer in order to use the galvanometer for measuring strength of currents.

It is most convenient and therefore customary to take for the known current that current strength which will cause a deflection of 45°. This is most convenient merely because the tangent of 45° is 1. This current that causes a deflection of 45° is called the **reduction factor** or **galvanometer constant.**

Each galvanometer, or, if it has more than one coil, each coil of a galvanometer, has its own reduction factor, which must be determined before the galvanometer can be used for measuring the strength of currents. The value of the reduction factor depends upon the number of turns of wire in the coil, the radius of the coil, and the strength of the earth's magnetic field where the galvanometer is set up.

To illustrate the use of the reduction factor, when once it is determined, let $k =$ the reduction factor, and $A°$ the deflection produced by a current of unknown strength represented by x. Then

$$k : x :: \tan 45° : \tan A°,$$
$$k : x :: 1 : \tan A°,$$
$$x = k \times \tan A°. \quad \text{Hence,}$$

The current = the reduction factor × the tangent of the angle of deflection.

Remarks on the Use of the Tangent Galvanometer

The instrument should be placed on a firm table where it will be as free as possible from disturbance and local iron influences, and where, if possible, it can remain undisturbed for an indefinite time. In placing the instrument, see that it is level, that the plane of the coil is in the magnetic meridian, and that the two ends of the pointer are at zero. When once adjusted in position, great care should be taken not to move it from its position.

Because of imperfect adjustment of the galvanometer, the needle, and its pointer, it often happens that the readings at the two ends of the pointer are not the same and do not agree with those given when the current is reversed. These errors, which should be small, may be caused by the pointer not being straight and at right angles to the needle, or by the axis on which the needle turns not being at the center of the graduated circle, or by the pointer not being adjusted to zero at both ends at first. To eliminate these errors, it is necessary to take double readings; that is, to read the position of each end of the pointer and then reverse the current and take the readings again. The average of the four readings taken must be considered as the true deflection.

The observer must be careful not to have any iron about his person. If a movement of the needle occurs upon the approach or retirement of the observer from the instrument, it is an indication that there is some iron or steel, such as knives, keys, or stays, about the clothing of the observer that will render accurate work impossible.

Parallax must be avoided by placing the eye above the needle so that the pointer hides its own image in the mirror beneath.

Whenever possible, it is best to arrange the apparatus or to select the coil of the galvanometer so that the deflection shall not vary widely from 45°, since the effect of an error in reading is less at that point than at any other. An error of 1° at 45° will produce an error of about 3.5 per cent in the result; while an error of the same amount at 10°, or 80°, will produce an error in the result of about 10 per cent.

To prevent the connecting wires from influencing the needle of the galvanometer, they should be twisted together where they approach the instrument.

For the explanation of the meaning of *tangent* of an *angle*, see page 94.

EXERCISE 69

REDUCTION FACTOR OF A TANGENT GALVANOMETER

Purpose. — *To measure the current passing through a tangent galvanometer by electrolysis and so to determine the galvanometer constant or reduction factor* (§§ 533, 537, 539).

Apparatus. — A tangent galvanometer. A watch. A battery of 2 or 3 storage cells, or one of from 4 to 6 Daniell cells. A voltameter; this is an electrolytic cell (Fig. 59) consisting of a deep jar full of water containing from 20 to 30 per cent of sulphuric acid. Two platinum electrodes are immersed in the liquid, the wires leading to these electrodes passing through glass tubes. Over the negative electrode, which may be simply a platinum wire, an inverted burette is placed as shown in Figure 59. A thermometer. A barometer. A commutator (Fig. 60).

All of the galvanometers in the laboratory may be connected in series with the voltameter and all standardized at the same time, the instructor taking part in the work. It is desirable also to include in the circuit a milammeter by which the instructor can check the work of the students.

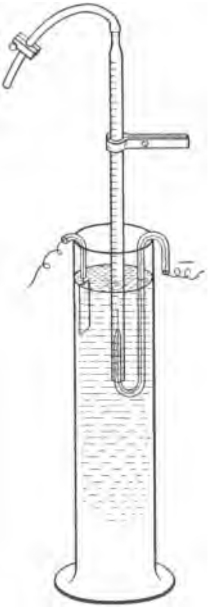


Fig. 59.

Procedure. — (1) The apparatus should be connected as shown by the diagram (Fig. 61). Let the pupils trace out the circuit, studying the commutator and the voltameter, and then let them draw a diagram in their notebooks representing the exact connections. The circuit should be closed to test the connections, and to test the strength of the current, before beginning actual work. The deflections of the galvanometer should be between 30° and 60°.

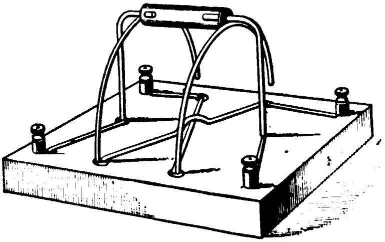


FIG. 60.

(2) Fill the burette by lowering it to the bottom of the jar and opening the pinchcock. Read the position of the water in the burette, having it as near as possible on a level with the water in the jar. Then lift it and support it over the negative electrode. Suspend a thermometer beside it.

(3) When all are ready, at a given signal, close the circuit at the commutator, those having watches noting the exact time.

(4) Observe the deflection of the needle at each end, and then reverse the current by the commutator and read the deflection again. Allow the current to flow for about fifteen minutes, or until 30 or 40 c.c. of hydrogen have been generated. Observe the needle carefully during this time, and keep the deflection and current constant by raising or lowering the burette over the negative electrode.

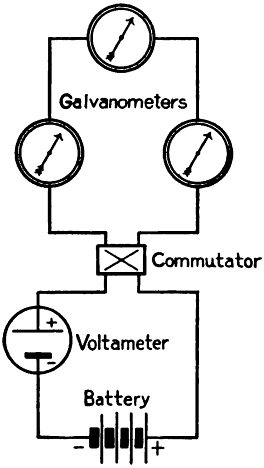


FIG. 61.

(5) Break the circuit at the commutator, noting the exact time at which it is done.

(6) Lower the burette till the level of the water inside

and out is the same, then read the height of the water in the burette. Also take the temperature and the barometer reading.

Record the results as follows:

Burette reading at first
Burette reading at end
Volume of hydrogen collected
Time of closing the circuit
Time of breaking the circuit
Time in seconds the current flowed
Deflections, direct
Deflections, reversed
Deflections, average
Tangent of average deflection
Temperature of the gas
Barometer reading
Correction for vapor tension
Corrected pressure
Volume of gas corrected for temperature and pressure
Volume of gas per second
Strength of current in amperes
Reduction factor

Discussion. — Since the burette contains water vapor as well as hydrogen, its presence is allowed for by finding its elastic tension from Table 16, Appendix. This tension opposes the atmospheric pressure and hence it is subtracted from the barometric pressure. This gives the corrected pressure.

The volume of hydrogen is then reduced to what it would be at 0° C. and 760 mm. pressure by Boyle's law and the law of Charles (§ 355).

Dividing the amount of hydrogen generated by the number of seconds the current flows gives the volume of hydrogen generated per second; and dividing the quotient thus obtained by 0.1155 gives the strength of the current in amperes flowing through the whole circuit, since one ampere flowing for one second (that is, one coulomb) liberates 0.1155 c.c. of hydrogen at 0° C. and 76 cm. pressure.

Then, by the law of the tangent galvanometer,

$$\left.\begin{matrix}\textit{the reduction}\\ \textit{factor}\end{matrix}\right\} : \begin{matrix}\textit{current}\\ \textit{used}\end{matrix} = \tan 45° : \left\{\begin{matrix}\textit{tan of average}\\ \textit{deflection}\end{matrix}\right. .$$

$$\textit{reduction factor} = \frac{\textit{current used}}{\textit{tangent of average deflection}}$$

because tan 45° = 1.

EXERCISE 70

ELECTROMOTIVE FORCE AND JOINING CELLS

Purpose. — *To measure the E.M.F. of two or more single cells, also the E.M.F. of the same cells joined in series and joined parallel in batteries.*

Apparatus. — ~~A~~ Two Daniell cells used as a standard of E.M.F., its E.M.F. being 1.1 volts. ~~Two or more~~ A dry cell~~s~~, ~~or~~ an other cell~~s~~ whose E.M.F.'s are to be measured. A high resistance, say 5000 ohms. A commutator. A D'Arsonval galvanometer provided with a shunt. If the deflection is too large, reduce the resistance of the shunt until the largest E.M.F. to be measured will not cause a deflection beyond the end of the scale (§ 500). The student should learn to use the galvanometer under the guidance of the instructor. If the zero of the scale is at its center, the average deflection is obtained by taking one half of the sum of two opposite deflections, no account being taken of the zero reading. If the zero of the scale is at its end, the average deflection is found by taking one half the difference of two opposite deflections.

Caution. — Do not allow the Daniell cell to stand on open circuit, but close the circuit by a wire of a few ohms' resistance.

Procedure.—(1) ~~Connect~~ Join the galvanometer to the commutator through the resistance box ~~apparatus as shown in Figure 62~~ and make a diagram of it in your notebook.

(2) Join the ~~wires A and B~~ opposite [illegible] of the commutator to the Daniell cell and obtain the average deflections, one in either direction.

(3) Join the wires to each of the other cells in turn and obtain the average deflection for each.

(4) Form a battery of the two Daniell cells ~~you have used~~ by joining them in series ~~(§ 502), and then join the wires A and B to this battery~~ and obtain the average deflection. Cells are joined in series by connecting the negative pole of the first cell to the positive of the second, the negative of the second to the positive of the third, etc. ~~In doing this the pupil is apt to short circuit the cells and polarize them; if he does this, all his previous work is of no value. The actual joining had better be done under the eye of the instructor.~~

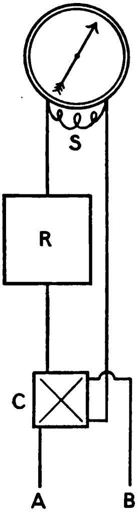


Fig. 62.

(5) Form a battery of the same cells by joining them parallel ~~(§ 503)~~ and obtain the average deflection. To join them parallel, connect all the negative poles together and attach wire *A* to them, and all the positive ones together and attach wire *B* to them.

Record the results as follows:

Volts per centimeter of deflection........						
Kind of Cell	No. of Cell	How Joined	Deflections			E.M.F. Obtained
			First	Second	Average	

continued on next page

Discussion. — This method of measuring E.M.F. is based on Ohm's law, $I = \frac{E}{R}$. By this law the current I is proportional to the electromotive force E, *if the resistance R is constant.* Therefore to use this method we must keep the resistance constant; but since the internal resistances of the different cells are not equal, the resistance of the circuit R is changed by a change of cells. To overcome this difficulty the high resistance is used in the circuit, so that the changes in resistance due to the use of different batteries will be such small fractions of the whole resistance that their effect on the result will be negligible. The resistance is practically constant, but not absolutely so.

The E.M.F. is proportional to the current, and the current to the deflection; hence the E.M.F. is proportional to the deflection. Therefore by forming proportions with the deflection and the E.M.F. of the Daniell cell and the deflection of the other cells you can calculate the E.M.F.'s of the other cells. It is better and it amounts to the same thing to divide the E.M.F. of the Daniel cell, 1.1, by the deflection of the Daniel cell and thus obtain the volts per centimeter of deflection. The E.M.F.'s of the other cells will then be obtained by multiplying their deflection by this quotient.

This galvanometer with the high resistance is virtually a *voltmeter*, lacking only a scale graduated in volts. It would be easy for you to make a scale for this galvanometer graduated in volts.

Commercial voltmeters are simply galvanometers of high resistance with scales reading in volts.

Compare the E.M.F. of the battery formed by the cells in series with the sum of the E.M.F.'s of the separate cells composing it. Compare the E.M.F. of the battery of parallel cells with the E.M.F.'s of each of the cells composing it. State the result in your notebook.

EXERCISE 71

OHM'S LAW

Purpose. — *To measure the fall of potential along a wire through which a constant current is flowing and to verify Ohm's law* (§ 497).

Apparatus. — A German silver wire *AO* (Fig. 63) about No. 25, a little more than 1 m. long, stretched upon a board. (The Wheatstone slide-wire bridge may be used.) A Daniell cell *B*. A commutator *C*. A high resistance *R*, say 5000 ohms. A block *D* having a strip of brass fastened to one side to which a wire is soldered; the sharp edge of this brass strip rests upon the wire at *P*, a weight being placed on the block *D* to ensure a firm contact. A D'Arsonval galvanometer without a shunt. The arrangement of the galvanometer with high resistance and commutator is the same as in

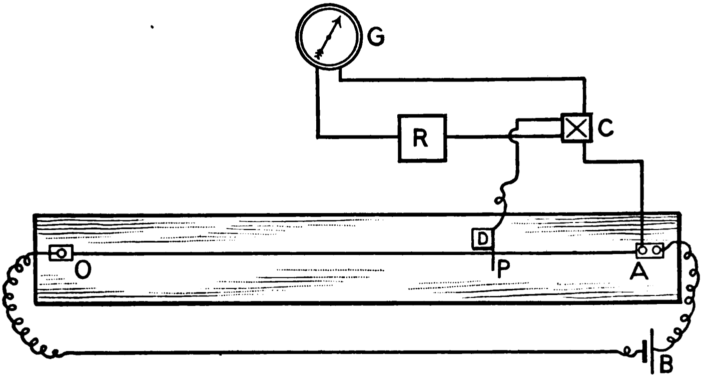


FIG. 63.

the last exercise, and it measures the potential difference between points on the wire AO just as it measured E.M.F. in that experiment.

Procedure. — (1) Connect the apparatus as shown in Figure 63 and draw a diagram of it in your notebook.

(2) Set the block D so that the point P is exactly 10 cm. from A and as soon as the galvanometer coil is at rest read the deflection as accurately as possible. Without moving D reverse the current through the galvanometer by means of the commutator and take the deflection again.

(3) Repeat the above, giving AP different values, as 20 cm., 30 cm., etc.

Record the results as follows:

DEFLECTION			LENGTH AP	$\frac{\text{DEFLECTION}}{\text{LENGTH } AP}$
First	Second	Average		

Discussion. — Throughout the experiment the current through the wire AO is supposed to be constant; if it is not very nearly so, the results will be of little value. It cannot be absolutely constant because currents of various values are taken from it at A and passed around through the galvanometer back to the wire AO at P. These currents through the galvanometer, however, are so extremely small on account of the resistance R that the errors due to it will not be perceptible in your results.

We have, then, two currents to consider, a constant current through the wire AOP and a variable current through the galvanometer.

The latter, due to the P.D. between *A* and *P*, is proportional to this P.D.; but the current through the galvanometer is also proportional to the deflection. Hence, the P.D.'s between *A* and *P* are proportional to the deflections.

Having studied out the meaning of the last column of your results, proceed on the principle that quantities proportional to the same quantities are proportional to each other and find the relation between the P.D.'s and the lengths *AP;* then between the lengths *AP* and the resistances between *A* and *P*; and finally between the P.D.'s from *A* to *P* and the resistances from *A* and *P*.

Plot a curve using the lengths *AP* and the deflections as coördinates. The relation which you ought to obtain between the P.D. and the resistance along the wire *when the current is constant*, is Ohm's law.

Note. — Should a tangent galvanometer be used, place another column in the table for the tangents of the angles of deflection and in the last column place the quotients of the tangents divided by lengths *AP*.

A voltmeter may be substituted for the galvanometer and resistance, and then the quotients of the readings of the instrument by the lengths *AP* should be placed in the last column.

EXERCISE 72

E.M.F. OF CELLS

Purpose. — *To measure E.M.F. of cells by a potentiometer.*

Apparatus. — A potentiometer, consisting of 6 m. of No. 28 German silver wire. A sensitive galvanometer, a D'Arsonval is best. A resistance box. Three or four Daniell cells and a cell whose electromotive force is to be determined. A movable contact key such as that used in Exercise 74.

Procedure. — (1) Connect the apparatus as shown in Figure 64, in which *E* is a single Daniell cell used as a standard of E.M.F. The battery at *L* must be of such strength and its internal resistance so proportioned to that of the wire of the potentiometer that the P.D. from *A* to *B* will be greater than the E.M.F. of any cell or battery to be placed at *E*. For testing cells no stronger than a Leclanché cell, two Daniell cells at *L* are sufficient. The same poles of the cell at *E* and of the battery at *L* must be connected to *A*. Make the resistance at *R* 100, or more, ohms, or as large as the sensitiveness of the galvanometer will permit.

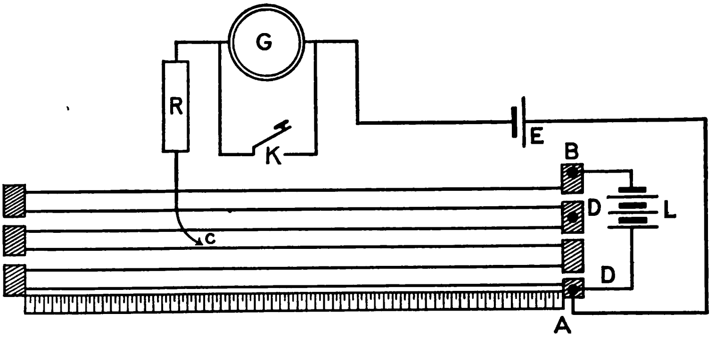


FIG. 64.

(2) As in Exercise 73, find a position for the sliding key *C*, on the wire of the rheochord, such that when it is closed there shall be no deflection of the galvanometer. Until the correct position for *C* is nearly attained, the key at *K* should be kept closed, to act as a shunt for the galvanometer. This key should also be closed between all trials, to bring the galvanometer to rest. The resistance at *R* should be as large as possible and yet have the galvanometer sensitive to a slight change of the position of *C*.

(3) Substitute for the Daniell cell that whose E.M.F. is to be measured, and again find a position for the sliding key *C* on the wire of the potentiometer that will cause no deflection of the galvanometer.

By placing two cells joined parallel, or in series, at *E*, their E.M.F. can be compared with that of one cell of the same kind.

The E.M.F.'s of the cells at *E* will be directly proportional to the length of the wire between *A* and *C*. For the E.M.F. of the Daniell cell use 1.1 volts.

Explanation. — The galvanometer circuit from *A* to *C* forms a shunt circuit in that of the battery at *L*, and the cell at *E* tends to set up a current in opposition to that from *L*, since the E.M.F. of the cell is in opposition to the P.D. on the wire. When *C* is closed at the right place on the wire, so that there is no current in the galvanometer circuit, it is the same as if it were not closed, because no current flows; and the E.M.F. of the cell at *E* just equals the P.D. between *A* and *C*. In Exercise 70 it was shown that the P.D. between *A* and *C* is proportional to the length of the wire between *A* and *C*. Hence the E.M.F. of the cells at *E* is proportional to the lengths of the wire from *A* to *C*. This holds true as long as the resistance of the circuit of *L* remains the same and the strength of the current from *L* is constant.

Record the data as follows:

CELLS AT *L*	CELL AT *E*	LENGTH, *A* TO *C*	E.M.F.

EXERCISE 73

RESISTANCE OF WIRES

Purpose. — *To measure the resistance of a conductor by means of a voltmeter and an ammeter* (§§ 495, 496).

Apparatus. — A Daniell cell or a dry cell. If the resistance is large and the other instruments not very sensitive, several cells may be needed. A voltmeter or the apparatus used in Exercise 69. An ammeter. A spool of copper wire of known length and diameter.

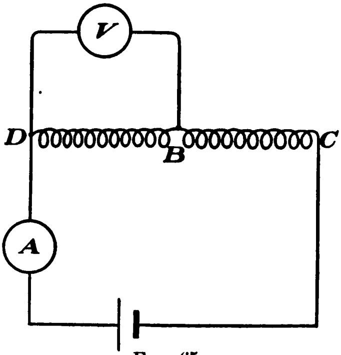


FIG. 65.

Procedure. — (1) Connect the battery, ammeter *A* (Fig. 65), and the resistance *DB* to be measured in series (if a dry battery is used, leave the circuit broken until just ready to make the observations). Join the voltmeter *V* as a shunt to the ends of the wire to be measured. Draw a diagram of the connections in your notebook.

(2) Close both the circuit of the voltmeter and that of the ammeter and read both instruments. The ammeter gives the strength of current through the wire and the voltmeter the P.D. between its ends.

Record the results as follows:

Kind of Wire	Length of Wire	Diameter	Volts	Amperes	Resistance Measured	Resistance from Table

Discussion. — By Ohm's law $R = E \div I$. Therefore dividing the number of volts observed by the number of amperes gives the resistance of the wire. From Table 20, Appendix, obtain the resistance of the wire and compare your result with it. If time permits, measure the resistance of a telegraph sounder, of an electric bell, or of a tangent galvanometer.

EXERCISE 74

RESISTANCE OF WIRES

Purpose. — *To measure resistance of wires by means of the Wheatstone slide-wire bridge* (§ 498).

Apparatus. — A D'Arsonval galvanometer having a shunt if it is very sensitive. A dry cell. A resistance box having coils of known resistance. Some spools of wire of known lengths and diameter. A Wheatstone slide-wire bridge. This consists of a heavy brass or copper strip $S'S'$ (Fig. 66) and two shorter ones S and S fasted upon a board. A German silver wire AB exactly a meter long is stretched from S to S and a meter stick is placed beside it. K is a movable key by which connection can be made at any desired point on the wire AB as at C.

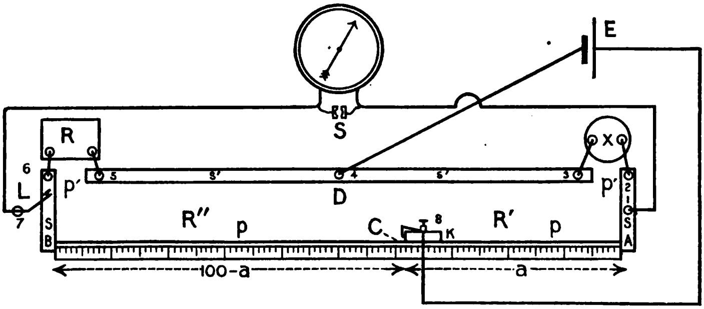


FIG. 66.

The cell is joined to the binding posts 4 and 8, the galvanometer to 1 and 7, the resistance to be measured *X* to 2 and 3, and the resistance box *R* to 5 and 6. *L* is a key to join the galvanometer to the strip *S*. The strips *S′S′* and *S* and *S* are broad and thick so that their resistances are practically zero.

Theory of the Bridge. — When the point *C* is correctly placed on the wire *AB*, and both keys *K* and *L* are closed, no current will flow through the galvanometer and the points *A* and *B* are at the same potential.

X is the resistance from *A* to *D*, and *R* the resistance from *D* to *B*. Let R' be the resistance of the wire from *A* to *C*, and R'' the resistance from *C* to *B*. *When no current flows through the galvanometer and A and B are at the same potential, these four resistances are proportional,* $R' : X = R'' : R$.

Proof. — Since *A* and *B* are at the same potential, the fall of potential from *C* to *A* is equal to that from *C* to *B*, because it is a fall from a common point to points of equal potential. Let *p* represent this P.D. Again, the fall from *A* to *D* equals that from *B* to *D*, because the fall is from points of equal potential to a common point. Let p' represent this P.D.

By Ohm's law (§ 497), $p : p' = R' : X$; also $p : p' = R'' : R$. Hence,

$$R' : X = R'' : R.$$

Since the resistance of a wire is proportional to its length, we can substitute for the resistances R' and R'' the lengths of the wire *AC* and *BC*, or *a* and $(100 - a)$; hence,

$$a : X = (100 - a) : R$$

and

$$X = R\frac{a}{100 - a}.$$

Procedure. — (1) Connect the apparatus as shown in the figure, using short, thick wires to join *R* and *X* to the bridge. Be sure that every binding post is screwed down tight. Draw a diagram of the apparatus in your notebook, lettering the parts *a*, 100 − *a*, *R*, and *X*.

Make the resistance *R* some known value, as 10 ohms, by removing the proper plug. See that the remaining plugs are tight.

(2) The operation of the bridge consists in finding the proper position for the point C so that the galvanometer gives no deflection when both keys K and L are closed. This is done by trial as follows:

First, place C at 10 cm. from A. With one hand on K and the other on L and the eye on the galvanometer, close K firmly and then L, *the latter only for an instant.* Note if there is a deflection and its direction. Repeat this with C at 20, 30, 40 cm., etc., from A, continuing until a point is found which gives an opposite deflection. If you cannot find such a point, something is wrong with the apparatus.

If, for example, all positions up to and including 60 give deflections to the left and 70 gives one to the right, the desired point is between 60 and 70. Having located the point within 10 cm., try each centimeter in that space in the same way as you did the 10 cm. spaces, until you find in what centimeter the point lies. Then try each millimeter in that centimeter. As the point is approached L must be closed longer.

(3) Having found the correct position for C, prove its correctness by trying points 1 mm. on each side of it. If you are right, you will get equal deflections in opposite directions. State and solve your proportion and calculate the resistance of X. (See Table 20, Appendix.)

In the above manner measure two or more wires of the same kind and diameter but of different lengths, and show that their resistances are proportional to their lengths. Also measure two or more wires of the same material and lengths but of different diameters, and show that their resistances are inversely proportional to the squares of their diameters.

Also join two wires which you have measured in parallel and measure their resistance, and show that it is equal to the reciprocal of the sum of their reciprocals (§ 500).

Also measure the same wire you measured in Exercise 73 and compare the two results.

Record the results as follows:

Kind of Wire	Gauge No.	Diameter in Mils	Diameter Squared	Length of Wire	a	$100-a$	R	X	K

See Table 20, Appendix, for diameter and square of diameter of the wire. Calculate the resistance of one foot of wire one mil in diameter for K.

EXERCISE 75

RESISTANCE OF CELLS

Purpose. — *To measure the internal resistance of a non-polarizing cell or battery.*

Apparatus. — A ~~milammeter~~ d'Arsonval galvanometer ~~whose resistance is so small as to be negligible or~~ whose resistance is known. A resistance box. Two Daniell cells ~~or two gravity cells, each cell being numbered.~~ Short thick wires having practically no resistance for connecting the apparatus.

Procedure. — (1) Join one cell, the ~~milammeter~~ galvanometer, and the resistance box in series, the resistance of the box being zero. Record the amount of deflection ~~current registered by the milammeter~~.

(~~If the current is too strong for the milammeter, add some resistance~~ by ~~means of~~ the ~~resistance box, considering this resistance as a~~ part of R in ~~the table.~~)

(2) If the resistance of the milammeter is zero, increase the resistance of the circuit by means of the resistance box until the current is just half as great as at first. Or, whether the resistance is zero or not, add a

definite resistance to the circuit, as 2, 3, or 5 ohms, and record the current.

(3) Substitute the other cell for the first one used and repeat the work.

(4) Join the two cells in series and repeat the work. Then join them parallel and repeat.

Record the results as follows:

Resistance of the milammeter, $R =$ ---------

No. of Cell	Kind of Cell	How Joined	Current I	Box Resistance R'	$R' + R$	Cell Resistance

Discussion. — $R' + R$ is the external resistance of the circuit and r the resistance of the cell or battery to be found.

If the current is made half as great as at first, the resistance of the circuit must by Ohm's law be doubled, the E.M.F. being unchanged; and if the resistance of the milammeter is zero, the only resistance in the circuit at first is that of the cell itself. Hence, when the resistance is doubled, the added resistance must equal the resistance of the cell.

If, however, you do not try to make the current just half as great as at first, but simply add a definite resistance, the resistance r may be calculated as follows:

By Ohm's law $I = \dfrac{E}{R' + R + r}$. By substituting the values obtained for I, R', and R in this equation, for the two cases you will have two independent equations with two unknown quantities, E and r. From these two equations, by elimination, the values of both E and r can be obtained.

Calculate the resistance of each cell, also of each battery, and compare the resistance of two cells in series with the resistance of one cell. Do the same with the cells joined parallel.

Again, assume the E.M.F. of the Daniell cell to be 1.1 volts, or of a gravity cell to be 0.98 volt, and from this and the current obtained calculate by Ohm's law the whole resistance of the circuit. If the external resistance is then subtracted from the whole resistance, the remainder will be the resistance of the cell or battery. In the battery of two cells in series the E.M.F. is to be taken as twice that of one cell.

EXERCISE 76

RESISTANCE AND E.M.F. OF A CELL

Purpose. — *To measure the resistance of a cell or battery by means of a tangent galvanometer.*

Apparatus. — A tangent galvanometer whose constant and resistance are known. A commutator. A resistance box. A Daniell or a gravity cell.

Procedure. — (1) Connect the instruments in series, and draw a diagram of them in the notebook.

(2) Make the resistance (R') of the resistance box such that the deflection shall be nearly 60°, and determine the average deflection.

(3) Change the resistance of the box so that the deflection shall be about 30°, designating the resistance in this case by R''. Determine the average deflection.

Discussion. — Ohm's law, $I = \frac{E}{R}$, indicates that I is inversely proportional to R when E is constant. In this experiment the R of the circuit is the sum of the resistances of the galvanometer, the box, and the cell. Let $g =$ the resistance of the galvanometer, and r that of the cell, R'

being that of the box in the first case, and R'' in the second case. Then in the first case the resistance of the circuit is $R'+g+r$, and in the second case $R''+g+r$. Let I and I' represent the currents in the two cases. Then

$$I : I' :: \frac{E}{R'+g+r} : \frac{E}{R''+g+r}.$$

But since the currents are proportional to the tangents of the angles of deflection, the tangents can be substituted for the currents in the above proportion.

Let A and $A' =$ deflections in the two cases.

Then, $\tan A : \tan A' :: \dfrac{1}{R'+g+r} : \dfrac{1}{R''+g+r}$,

from which the value of r can be determined.

Galvanometer				**Coils Used**			
Galvanometer Constant				**Galvanometer Resistance, g**			
KIND OF CELL	BOX RESISTANCE R' OR R''	DEFLECTIONS			TANGENTS	CURRENTS	CELL RESISTANCE, r
		Direct	Reverse	Average			

EXERCISE 77

CURRENT INDUCTION

Purpose. — *To study currents induced by means of a magnet.*

Apparatus. — A D'Arsonval galvanometer, a bar magnet, a spool or coil having about 800 turns of copper wire, about No. 28, a small strip of zinc and a tumbler of distilled water, a rod of soft iron (§§ 510, 511, 512).

Procedure. — (1) Twist the bare end of one of the galvanometer wires around the strip of zinc. Dip this zinc into the water and also the bare end of the other galvanometer wire; this copper wire, the water, and the zinc make a very weak cell. If it is not strong enough to give a noticeable deflection, add a grain of common salt to it.

Record in tabular form whether the current enters the right or the left terminal of the galvanometer. Also record the direction of the deflection, whether it is to the right or left. This will enable you to know in the future the direction of any current through this galvanometer.

(2) Remove the cell and join the spool of wire to the galvanometer. With the eye on the galvanometer thrust the *N* pole of the bar magnet into the spool of wire, leaving it there. If a current is produced, how long does it last? Such a current is said to be caused by induction. If you prefer, you may move the coil and keep the magnet stationary.

(3) Repeat No. 2, observing the deflection and determining the direction of the current through the galvanometer. Then (*a*) by following the wires to and around the spool trace out the direction of the current around the spool; then (*b*) thrust a *S* pole into the spool; then (*c*) withdraw the *N* pole; and last (*d*) withdraw the *S* pole. Trace out the direction of the current around the

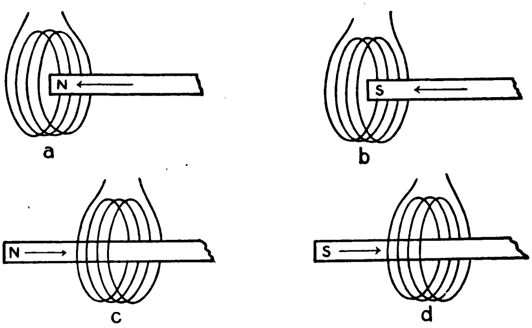


FIG. 67.

spool in each case and record the results by drawing diagrams like those of Figure 68 and placing arrowheads on the wires to indicate the directions of the currents.

(4) Grasp the coil so that the fingers extend through it in the same direction as the lines of force did in each of the above cases, using the left hand when the lines of force through it were increased and the right hand for those cases in which they were decreased by the movement of the magnet. Compare the direction of the currents induced with the direction the thumb points in each case.

Formulate a rule by which you can tell the direction of an induced current in a coil by the use of the hand, if you know the direction of the lines of force.

(5) In each case consider the coil a temporary electromagnet. In (*a*) and (*b*) is the end of the coil toward which the magnet moves like or unlike the pole of the magnet used? Would it oppose or help the motion?

In (*c*) and (*d*) is the end of the spool where the magnet leaves it like or unlike the pole of the magnet withdrawn? Would it oppose or help the motion?

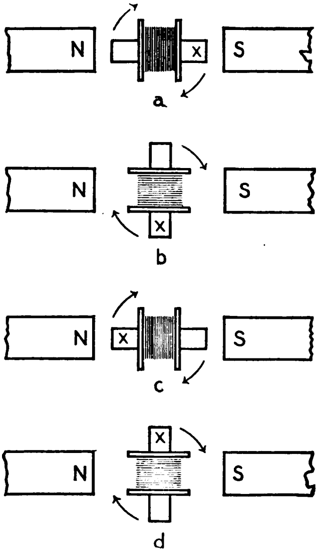


FIG. 68.

(6) Support two magnets on books on the table, as shown in Figure 69, and place the coil between them with the rod of soft iron within it. Place it first in position (*a*) and turn it quickly about a vertical axis to position (*b*), noting the direction of the deflection. After the galvanom-

eter coil has come to rest, turn the coil to position (*c*) and note the deflection; then turn it to position (*d*); and lastly to position (*a*), thus making a complete revolution. Try it again without the iron core.

If the coil were rotated continuously in this way, what parts of the revolution would produce currents in one way, and what parts in the other direction? At what points in the revolution would the current change direction? How many times in each revolution would the current change direction? What kind of a current would it be called? This experiment illustrates the principle of the dynamo.

Record the results as follows:

Current entering the galvanometer on the................

Deflection of galvanometer is toward the................

(*a*) Poles are ....motion is................

(*b*) Poles are................motion is ....

(*c*) Poles are................motion is ....

(*d*) Poles are................motion is................

NOTE.—Insert *alike* or *unlike* after "are" and *helped* or *opposed* after "is."

EXERCISE 78

CURRENT INDUCTION

Purpose. — *To study currents induced in one coil by means of currents in another coil* (§§ 524, 525).

Apparatus. — Two spools or coils of wire each having about 800 turns of wire. A d'Arsonval galvanometer. A battery of one or two dry cells. A rod of soft iron. A commutator.

Procedure. — (1) Join one of the spools of wire to the battery through the commutator, leaving the circuit open at the commutator until all is ready; this spool is the

primary. Join the other spool to the galvanometer; this is the **secondary** coil.

Complete the circuit of the primary coil and determine the direction of the current around the spool by placing a compass within it and noting the deflection. Mark this direction on the spool by an arrowhead.

(2) With the eye on the galvanometer, bring the two spools quickly together end to end and hold them there. If a current is induced in the secondary, tell how long it lasts; also trace out its direction and record whether it is in the same or opposite direction as that in the primary.

(3) With the eye on the galvanometer quickly separate the two spools. Note and record the results as before.

(4) Place the spools together again and break the circuit of the primary, recording the results as before at the instant the circuit is broken. Do the same at the instant the circuit is made again.

Make and break the circuit as rapidly as you can. What kind of a current is induced in the secondary?

(5) Place the rod of soft iron through one of the spools and repeat the work from the beginning. In addition alternate the current in the primary as rapidly as you can by means of the commutator. In the last case what kind of a current is induced in the secondary?

What is the effect of the soft iron? Can you see that magnetic lines of force have to do with this experiment the same as in the last?

(6) If a pair of old horseshoes can be obtained, place the arm of one of them through the two spools in one direction and that of the other shoe through the spools in the opposite direction, so that the two shoes form an iron ring or a complete path of iron for the lines of force.

Repeat the work again of paragraph 4, also alternate the current in the primary as rapidly as possible as in paragraph 5. Note the effect of having a complete path of iron for the lines of force.

This arrangement with the horseshoes illustrates the principle of the transformer (§ 525).

The procedure of paragraph 4 illustrates the induction coil (§ 528). If possible, let the student examine an induction coil and study its principle of operation. It should be observed that the two coils, primary and secondary, may occupy any position relative to each other, provided that the lines of force of one coil extend through the other.

Record the results as follows :

Procedure	Results in Secondary
Coils brought together	
Coils stationary	
Coils separated	
Current made in primary	
Current broken in primary	
Current alternated in primary	
Effect of iron core	

APPENDIX

NOTES AND SUGGESTIONS

SINCE it is possible to buy apparatus for the high school laboratory at reasonable prices and much better apparatus than the teacher ordinarily can make, instructions for making apparatus have in the main been omitted from this appendix. It has been thought best to introduce a few useful hints about some of the exercises and about the apparatus, which are intended for the teacher only and which would confuse the pupil if embodied in the text.

THE NOTEBOOK

The notebook is one of the most difficult problems of the physics teacher. The author believes that any system of taking notes that permits a pupil to copy and discard the original notes encourages careless and slovenly, if not dishonest, work. For that reason temporary notebooks, sheets of paper, and even loose-leaf notebooks are unsatisfactory.

The following method with notebooks has been found very satisfactory. Let the original notes be taken in pencil in the permanent notebook, then let them be copied in ink on the following pages of the same book. All the calculations should be made in the notebook and not on scraps of paper; they are useful for reference. Neatness and accuracy in these temporary notes should be taught, and corrections of mistakes by disfiguring the book in any way should be frowned upon. If the notebook is taken from the laboratory at the close of the hour, the work should be examined and approved or signed by the instructor before it is taken away.

Although such a book does not look quite so well as one with no temporary notes in it, it is really a better book, and the instructor can conscientiously certify that it contains the original notes of the pupil for those colleges that demand it.

Much more attention than is usual should be given to doubtful figures. It requires courage sometimes on the part of older people to reject figures of unknown value. The pupil will have much more respect for his work if he is taught correctly in this regard.

EXERCISE 13

This exercise often proves unsatisfactory largely because of the errors of the balances, but chiefly because the fractions of units of force cannot be estimated at all accurately. This last trouble may be overcome by adjusting the apparatus so that all the readings shall be exact whole numbers. Let the bar be made of a meter stick cut in two lengthwise. Dress this bar down until with its wire hooks it weighs exactly 60 g., or until the bar with no weight upon it registers an exact whole number of grams in each balance.

EXERCISE 14

The pendulum clamp shown in Figure 15, p. 42, is made of two pieces of brass, each $\frac{3}{4}$ in. wide and $\frac{3}{16}$ in. thick. *a* is 1 in. and *b* 2 in. long. The pin *c* and the screw *e* pass through *b*, and are soldered in place; but the holes through *a* are large enough to allow it to move freely upon *c* and *e*. The thread of the pendulum can be passed over the pin *c*, which may be used as a pulley when changing the length of the pendulum.

EXERCISE 17

Excellent results are possible for this exercise. Be sure that the table is level. Usually the pupil makes greater errors in measuring the length and height of the plane than in obtaining the weights. To measure the height of the plane use a meter stick fastened to a base so that it will stand on the table perpendicular to it.

EXERCISE 23

For measuring the heights *AD* and *BE*, it is best to have a meter stick arranged as described in the last paragraph.

The mercury is easily introduced into the tube by pushing a fine iron wire, such as a piece of piano wire, down the tube. The mercury will flow to the end of the wire. By means of the wire the mercury thread may be moved to any desired position and its parts united, if it is broken.

EXERCISE 28

For a sinker for this exercise fuse a platinum wire into a piece of glass rod about $\frac{3}{8}$ in. in diameter and 2 in. long. The advantage of such a sinker is that the specific gravity of the liquids can be determined without taking them from the bottles in which they are kept, as the sinker can be lowered into the liquid through the mouth of the bottle.

EXERCISE 34

The number of holes in the circles of the given disk should be in such proportion that the notes of the musical scale will be produced, beginning with the inner circle and going toward the circumference of the disk. Twenty-four holes is perhaps the best number for the inner circle. A good disk can be made from a sheet of tin.

EXERCISE 46

The focal length of the mirror in this exercise should not exceed about 12 cm. It is difficult to locate images by the microscope if the focal length is large.

EXERCISE 53

The bore of the tube for this exercise should not be more than 2 mm. in diameter. The tube should be about 40 cm. long. The mercury is introduced into it by the aid of an iron wire as explained for Exercise 23. Long threads of mercury are more apt to break than short ones.

To introduce the sulphuric acid, make a funnel by drawing out a piece of glass tubing into a thread about a millimeter in diameter and long enough to reach nearly to the bottom of the expansion tube. Insert this capillary tube into the large tube, and place in the enlarged upper part of it a few drops of the acid by a medicine dropper. It will slowly work its way down into the tube.

EXERCISE 54

Aluminum rods 1 in. in diameter can be obtained through the hardware dealer. For the mass to be used with aluminum calorimeter, cut from such a rod with a hack saw a cylinder about 3 in. long. If a copper calorimeter is used, cut from a copper rod 1 in. in diameter a cylinder about 2 in. long.

Aluminum liquor shakers of about 500 c.c. make excellent calorimeters and can be obtained at very reasonable prices.

EXERCISE 69

If the radius a of a coil in centimeters, the number n of turns of wire in the coil, and the horizontal intensity H of the earth's magnetism are known, then the reduction factor C in amperes can be found by the following formula:

$$C = \frac{10\,Ha}{2\,n\pi}.$$

This formula applies to 45° only.

H in the northern part of the United States is about 0.18 dyne. Isodynamic charts can be obtained from the U. S. Coast and Geodetic Survey which give the value of H for all parts of the United States.

EXERCISE 70

A high resistance of 5000 to 15,000 ohms may be made by covering the roughened surface of a piece of hard rubber with a very thin layer of a mixture of insulating varnish and graphite. After the first coat is dry add another coat until the resistance is reduced to that desired. The piece of rubber should be about 6 × 3 cm. and should be mounted on a block and held in place by a binding post at each end. A strip of brass should be placed under each binding post. (Ajax insulating varnish made by the Sherwin Williams Co., Cleveland, Ohio, is excellent.)

The Daniell Cell. — Make up a 5 per cent solution of zinc sulphate, and, when the cell is to be used, fill the porous cup with it, placing the cell on a circuit of a few ohms resistance for several minutes before using it. The zinc should be thoroughly amalgamated. When the cell is not in use, the zinc sulphate should be turned out of the porous cup, which should be kept in water. Be sure that the copper sulphate solution is kept saturated by always having some crystals in the pocket on the copper plate.

A Tuning Fork suitable for laboratory exercises can be made by a blacksmith out of steel $\frac{1}{8}$ in. thick and $\frac{3}{4}$ in.

wide. The prongs should be about 6 in. long and should be left soft at the ends, so that they can be filed away for adjustment.

To bend Glass Tubing. — Hold the tube in the flat luminous flame of an ordinary gas burner so that it will be heated for about 3 in. of its length, constantly turning the tube about in the fingers. As soon as it has softened, remove it from the flame and bend it quite quickly. When it is cold, remove the soot by a damp cloth.

Boring Glass. — Use an awl or tool having a rounded wedge-shaped point, —a point much like that of a pegging awl, but much more blunt. Place a piece of thick sheet lead under the glass at the point where the hole is to be bored, and moisten the tool with a solution made of 8 parts by weight of camphor, 16 parts of turpentine, and 3 parts of ether.

By giving a twisting motion to the awl or tool, a hole is quickly and easily made through the glass.

Soldering. — Success in soldering depends upon three things: first, the surfaces to be soldered must be clean; second, they must be held firmly in position; and third, they must be heated sufficiently hot to allow the solder to flow. If a soldering iron is used, it must be clean and well tinned.

The ordinary soldering fluid is made by dissolving zinc in hydrochloric acid, but this is liable to absorb moisture and corrode the parts. It should always be washed off as thoroughly as possible. Non-corrosive soldering pastes or fluxes may be had of the electrician.

A Useful Cement is made by mixing 1 part of gutta percha and one part of pine-pitch at 100° C., stirring it thoroughly together.

TABLE 1

METRIC EQUIVALENTS

1 m.	= 39.37 in.	1 in.	= 2.5400 cm.
1 m.	= 3.2809 ft.	1 ft.	= 30.480 cm.
1 m.	= 1.0936 yd.	1 yd.	= 0.91440 m.
1 km.	= 0.62137 mi.	1 mi.	= 1.60933 km.
1 sq. cm.	= 0.1550 sq. in.	1 sq. in.	= 6.4515 sq. cm.
1 sq. m.	= 10.764 sq. ft.	1 sq. ft.	= 929.01 sq. cm.
1 sq. m.	= 1.196 sq. yd.	1 sq. yd.	= 0.83615 sq. m.
1 cc.	= 0.06102 cu. in.	1 cu. in.	= 16.387 c.c.
1 cu. m.	= 35.314 cu. ft.	1 cu. ft.	= 28,316 c.c.
1 cu. m.	= 1.3080 cu. yd.	1 fluid oz.	= 29.571 c.c.
1 l.	= 0.26417 gal.	1 liquid qt.	= 0.94636 l.
1 l.	= 0.90827 dry qt.	1 dry qt.	= 1.101 l.
1 g.	= 15.43236 gr.	1 gr.	= 0.0648 g.
1 kg.	= 2.2046 lb. avoir.	1 lb. avoir.	= 453.59 g.
1 g.	= 0.035274 oz.	1 oz. avoir.	= 28.3495 g.

TABLE 2

USEFUL NUMBERS AND FORMULAS

$\pi = 3.1416$, $\pi^2 = 9.8696$, $\frac{1}{\pi} = 0.31831$, $\frac{\pi}{4} = 0.7854$, $\log \pi = 0.4971499$, $\sqrt{\pi} = 1.77245$.

Circumference of a circle (radius r) $= 2\pi r$.

Area of circle (radius r) $= \pi r^2$.

Surface of a sphere (radius r) $= 4\pi r^2 =$ diam. × circum.

Volume of a sphere (radius r) $= \frac{4}{3}\pi r^3$.

Volume of right cylinder (height h, base πr^2) $= \pi r^2 h$.

$\sqrt{2} = 1.4142$, $\sqrt{3} = 1.7320$, $\sqrt{5} = 2.2361$, $\sqrt{10} = 3.16228$, $\sqrt{\frac{1}{2}} = .7071$.

TABLE 3

DENSITIES OF SUBSTANCES IN GRAMS PER CUBIC CENTIMETER

Agate	2.615	Granite	2.650
Alcohol, absolute	0.806	Graphite	2.500
Alcohol, common	0.833	Gun-metal	8.561
Aluminum	2.670	Hydrochloric acid, aq. sol.	1.222
Antimony, cast	6.720	Ice	0.917
Ash, dry	0.690	Iron, bar	7.788
Asphalt	2.500	Iron, cast	7.230
Beeswax	0.964	Iron, wrought	7.780
Bell metal	8.050	Iron pyrites	5.000
Benzine	0.72 to 0.740	Ivory	1.820
Bismuth, cast	9.822	Lead, cast	11.360
Boxwood	1.280	Lead, sheet	11.400
Brass, cast	8.400	Lignum vitæ	1.333
Brass, sheet	8.440	Limestone	3.180
Brick	1.6 to 2.000	Mahogany	0.56 to 0.852
Cedar, American	0.554	Maple	0.755
Chalk	1.8 to 2.800	Marble	2.720
Cherry	0.710	Mercury	13.596
Coal, anthracite	1.26 to 1.800	Nitric acid	1.38 to 1.559
Coal, bituminous	1.270 to 1.423	Oak, American red	0.850
Cork	0.240	Oak, American white	0.779
Copper, cast	8.830	Oil, turpentine	0.870
Copper, sheet	8.878	Paraffine	0.824 to 0.940
Diamond	3.530	Petroleum	0.836
Ebony	1.187	Phosphorus	1.830
Emery	3.900	Pine, white, dry	0.554
Ether	0.736	Platinum wire	21.531
Fir, spruce	0.512	Porcelain, china	2.380
Fluor-spar	3.200	Quartz	2.650
Galena	7.580	Silver, cast	10.424 to 10.511
German-silver	8.432	Steel, unhammered	7.816
Glass, flint	3.000 to 3.600	Sulphur, native	2.033
Glass, crown	2.520	Sulphuric acid	1.840
Glass, plate	2.760	Tin, cast	7.290
Glycerine	1.260	Walnut	0.680
Gold	19.360	Water, sea	1.027
Gypsum, crys.	2.310	Zinc, cast	7.000

TABLE 4

THE DENSITY AND VOLUME OF WATER AT VARIOUS TEMPERATURES

Temperature C.	Volume of 1 g. in cc.	Density or Mass of 1 cc.	Temperature C.	Volume of 1 g. in cc.	Density or Mass of 1 cc.
0	1.0001269	0.999873	19	1.00158	0.998422
1	1.0000730	0.999927	20	1.00179	0.998213
2	1.0000331	0.999966	21	1.00200	0.998004
3	1.0000083	0.999999	22	1.00222	0.997784
4	1.0000000	1.000000	23	1.00244	0.997566
5	1.0000082	0.999999	24	1.00271	0.997297
6	1.0000309	0.999969	25	1.00293	0.997078
7	1.0000708	0.999929	26	1.00321	0.996800
8	1.0001216	0.999878	27	1.00345	0.996562
9	1.0001879	0.999812	28	1.00374	0.996274
10	1.0002684	0.999731	29	1.00403	0.995986
11	1.0003598	0.999640	30	1.00433	0.995688
12	1.0004724	0.999527	40	1.00773	0.992329
13	1.0005862	0.999414	50	1.01205	0.988093
14	1.0007146	0.999285	60	1.01698	0.983303
15	1.0008751	0.999125	70	1.02255	0.977947
16	1.0010215	0.998979	80	1.02885	0.971959
17	1.0012067	0.998794	90	1.03566	0.965567
18	1.00139	0.998612	100	1.04315	0.958634

1 cu. in. of water at 16 C. weighs 0.577 oz. avoir.

TABLE 5

ACCELERATION *g* DUE TO GRAVITY AND LENGTH *l* OF THE SECONDS PENDULUMS FOR DIFFERENT LATITUDES

Lat.	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°
g	978.1	978.2	978.7	979.3	980.2	980.62	981.1	981.9	982.6	983.0	983.2
l	99.10	99.12	99.15	99.23	99.31	99.36	99.40	99.49	99.56	99.60	99.62 cm.

TABLE 6

Reduction of Barometer Reading to 0° C.

Subtract the correction.

Temperature	Millimeters									
	680	690	700	710	720	730	740	750	760	770
C.°	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
10	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.22	1.23	1.25
11	1.21	1.23	1.25	1.27	1.28	1.30	1.32	1.34	1.35	1.37
12	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.48	1.50
13	1.43	1.45	1.47	1.50	1.52	1.54	1.56	1.58	1.60	1.62
14	1.54	1.56	1.59	1.61	1.63	1.66	1.68	1.70	1.72	1.75
15	1.65	1.68	1.70	1.73	1.75	1.77	1.80	1.82	1.85	1.87
16	1.76	1.79	1.81	1.84	1.87	1.89	1.92	1.94	1.97	2.00
17	1.87	1.90	1.93	1.96	1.98	2.01	2.04	2.07	2.09	2.12
18	1.98	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.22	2.25
19	2.09	2.12	2.15	2.19	2.22	2.25	2.28	2.31	2.34	2.37
20	2.20	2.24	2.27	2.30	2.33	2.37	2.40	2.43	2.46	2.49
21	2.31	2.35	2.38	2.42	2.45	2.48	2.52	2.55	2.59	2.62
22	2.42	2.46	2.49	2.53	2.57	2.60	2.64	2.67	2.71	2.74
23	2.53	2.57	2.61	2.65	2.68	2.72	2.76	2.79	2.83	2.87
24	2.64	2.68	2.72	2.76	2.80	2.84	2.88	2.92	2.95	2.99
25	2.75	2.79	2.84	2.88	2.92	2.96	3.00	3.04	3.08	3.12
26	2.86	2.91	2.95	2.99	3.03	3.07	3.12	3.16	3.20	3.24
27	2.97	3.02	3.06	3.11	3.15	3.19	3.24	3.28	3.32	3.37
28	3.08	3.13	3.18	3.22	3.27	3.31	3.36	3.40	3.45	3.49
29	3.19	3.24	3.29	3.34	3.38	3.43	3.48	3.52	3.57	3.62
30	3.30	3.35	3.40	3.45	3.50	3.55	3.60	3.65	3.69	3.74

TABLE 7

Average Height *b* of Barometer at Elevation *H* above Sea Level (10° C.)

H	H	b	b	H	H	b	b
meters	feet	mm.	inches	meters	feet	mm.	inches
0	0	760	29.92	1000	3280	674	26.53
100	328	751	29.57	1100	3608	666	26.22
200	656	742	29.21	1200	3936	658	25.90
300	984	733	28.85	1300	4265	650	25.59
400	1312	724	28.50	1400	4592	642	25.27
500	1640	716	28.19	1500	4920	635	25.00
600	1968	707	27.83	1600	5248	627	24.68
700	2296	699	27.52	1700	5577	620	24.41
800	2624	690	27.17	1800	5905	612	24.09
900	2952	682	26.85	1900	6233	605	23.82
1000	3280	674	26.53	2000	6561	598	23.54

TABLE 8

REDUCTION OF BAROMETER READING TO 32° F.

Tempera-ture	Inches								
	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0
50	-0.052	-0.053	-0.054	-0.055	-0.056	-0.057	-0.058	-0.059	-0.060
51	0.055	0.056	0.057	0.058	0.059	0.060	0.061	0.062	0.063
52	0.057	0.058	0.059	0.060	0.061	0.062	0.064	0.065	0.066
53	0.060	0.061	0.062	0.063	0.064	0.065	0.066	0.067	0.068
54	0.062	0.063	0.064	0.065	0.067	0.068	0.069	0.070	0.071
55	0.064	0.065	0.066	0.068	0.069	0.070	0.071	0.073	0.074
56	0.067	0.068	0.069	0.070	0.072	0.073	0.074	0.075	0.077
57	0.069	0.070	0.072	0.073	0.075	0.076	0.077	0.078	0.080
58	0.071	0.073	0.074	0.076	0.077	0.078	0.080	0.081	0.082
59	0.074	0.075	0.077	0.078	0.080	0.081	0.083	0.084	0.085
60	0.077	0.078	0.079	0.081	0.082	0.084	0.085	0.086	0.088
61	0.079	0.080	0.082	0.083	0.085	0.086	0.088	0.089	0.091
62	0.082	0.083	0.085	0.086	0.088	0.089	0.091	0.092	0.094
63	0.084	0.085	0.087	0.088	0.090	0.091	0.093	0.095	0.096
64	0.086	0.088	0.090	0.091	0.093	0.094	0.096	0.097	0.099
65	0.089	0.090	0.092	0.093	0.095	0.097	0.099	0.100	0.102
66	0.091	0.093	0.095	0.096	0.098	0.099	0.101	0.103	0.105
67	0.094	0.095	0.097	0.099	0.101	0.102	0.104	0.106	0.108
68	0.096	0.098	0.100	0.101	0.103	0.105	0.107	0.108	0.110
69	0.099	0.100	0.102	0.104	0.106	0.107	0.110	0.111	0.113
70	0.101	0.103	0.105	0.106	0.109	0.110	0.112	0.114	0.116
71	0.103	0.105	0.107	0.109	0.111	0.113	0.115	0.116	0.119
72	0.106	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122
73	0.108	0.110	0.112	0.114	0.116	0.118	0.120	0.122	0.124
74	0.111	0.113	0.115	0.117	0.119	0.121	0.123	0.125	0.127
75	0.113	0.115	0.117	0.119	0.122	0.124	0.126	0.128	0.130
76	0.116	0.118	0.120	0.122	0.124	0.126	0.128	0.130	0.133
77	0.118	0.120	0.122	0.124	0.127	0.129	0.131	0.133	0.136
78	0.120	0.122	0.125	0.127	0.129	0.131	0.134	0.136	0.138
79	0.123	0.125	0.127	0.129	0.132	0.134	0.137	0.139	0.141
80	0.125	0.127	0.130	0.132	0.135	0.137	0.139	0.141	0.144
81	0.128	0.130	0.132	0.134	0.137	0.139	0.142	0.144	0.147
82	0.130	0.132	0.135	0.137	0.140	0.142	0.145	0.147	0.149
83	0.133	0.135	0.138	0.140	0.142	0.145	0.147	0.149	0.152
84	0.135	0.138	0.140	0.142	0.145	0.147	0.150	0.152	0.155
85	0.137	0.139	0.143	0.145	0.148	0.150	0.153	0.155	0.158
86	0.140	0.143	0.145	0.148	0.150	0.153	0.155	0.158	0.161
87	0.142	0.144	0.148	0.150	0.153	0.155	0.158	0.161	0.163
88	0.145	0.147	0.150	0.152	0.155	0.158	0.161	0.163	0.166
89	0.147	0.150	0.153	0.155	0.158	0.161	0.164	0.166	0.169
90	0.150	0.153	0.155	0.157	0.161	0.164	0.166	0.169	0.172
91	0.152	0.155	0.158	0.160	0.163	0.166	0.169	0.172	0.175
92	0.154	0.157	0.160	0.163	0.166	0.169	0.172	0.175	0.177
93	0.157	0.160	0.163	0.166	0.168	0.171	0.174	0.177	0.180
94	0.159	0.162	0.165	0.168	0.171	0.174	0.177	0.180	0.183

TABLE 9

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA LEVEL, CORRECTION IN INCHES ADDITIVE

Height, in Feet, above Sea	Temperature of External Air — Degrees Fahrenheit										
	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
10	0.013	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.010	0.010
20	0.025	0.025	0.024	0.023	0.023	0.023	0.022	0.022	0.021	0.021	0.020
30	0.038	0.037	0.036	0.035	0.034	0.034	0.033	0.032	0.032	0.031	0.030
40	0.050	0.049	0.048	0.047	0.046	0.045	0.044	0.043	0.042	0.041	0.040
50	0.063	0.061	0.060	0.059	0.058	0.056	0.055	0.054	0.053	0.052	0.051
60	0.076	0.074	0.072	0.070	0.069	0.068	0.066	0.065	0.063	0.062	0.061
70	0.088	0.086	0.084	0.082	0.081	0.078	0.077	0.076	0.074	0.072	0.071
80	0.101	0.098	0.096	0.094	0.092	0.090	0.088	0.086	0.084	0.082	0.081
90	0.113	0.111	0.108	0.105	0.104	0.101	0.099	0.097	0.095	0.093	0.091
100	0.126	0.123	0.120	0.117	0.115	0.112	0.110	0.108	0.105	0.103	0.101
110	0.139	0.135	0.132	0.129	0.126	0.123	0.121	0.119	0.116	0.113	0.111
120	0.151	0.148	0.144	0.140	0.138	0.134	0.132	0.129	0.126	0.124	0.121
130	0.164	0.160	0.156	0.152	0.149	0.146	0.143	0.140	0.137	0.134	0.131
140	0.176	0.172	0.168	0.164	0.161	0.157	0.154	0.151	0.147	0.144	0.141
150	0.189	0.185	0.180	0.176	0.172	0.168	0.165	0.162	0.158	0.155	0.152
160	0.201	0.197	0.192	0.187	0.183	0.179	0.176	0.172	0.168	0.165	0.162
170	0.214	0.209	0.204	0.199	0.195	0.190	0.187	0.183	0.179	0.175	0.172
180	0.227	0.222	0.216	0.211	0.206	0.202	0.198	0.194	0.189	0.185	0.182
190	0.239	0.234	0.228	0.222	0.218	0.213	0.209	0.204	0.200	0.196	0.192
200	0.252	0.246	0.240	0.234	0.229	0.224	0.220	0.215	0.210	0.206	0.202
210	0.264	0.258	0.252	0.246	0.240	0.235	0.231	0.226	0.221	0.216	0.212
220	0.277	0.270	0.264	0.257	0.252	0.246	0.242	0.236	0.231	0.227	0.222
230	0.289	0.283	0.276	0.269	0.263	0.257	0.253	0.247	0.242	0.237	0.232
240	0.302	0.295	0.288	0.281	0.275	0.269	0.264	0.258	0.252	0.248	0.242
250	0.314	0.307	0.300	0.293	0.286	0.280	0.275	0.269	0.263	0.258	0.253
260	0.327	0.319	0.311	0.304	0.297	0.291	0.285	0.279	0.273	0.268	0.263
270	0.339	0.331	0.323	0.316	0.309	0.302	0.296	0.290	0.284	0.278	0.273
280	0.352	0.344	0.335	0.328	0.320	0.314	0.307	0.301	0.294	0.288	0.283
290	0.364	0.356	0.347	0.339	0.332	0.325	0.318	0.311	0.305	0.299	0.293
300	0.377	0.368	0.359	0.351	0.343	0.336	0.329	0.322	0.315	0.309	0.303
310	0.389	0.380	0.371	0.363	0.354	0.347	0.340	0.333	0.326	0.319	0.313
320	0.402	0.392	0.383	0.374	0.366	0.358	0.351	0.343	0.336	0.329	0.323
330	0.414	0.404	0.395	0.386	0.377	0.369	0.362	0.354	0.347	0.340	0.333
340	0.427	0.416	0.407	0.397	0.389	0.380	0.373	0.365	0.357	0.350	0.343
350	0.439	0.429	0.419	0.409	0.400	0.392	0.384	0.376	0.368	0.360	0.353
360	0.451	0.441	0.430	0.421	0.411	0.403	0.394	0.386	0.378	0.370	0.363
370	0.464	0.453	0.442	0.432	0.423	0.414	0.405	0.397	0.389	0.380	0.373
380	0.476	0.465	0.454	0.444	0.434	0.425	0.416	0.408	0.399	0.391	0.383
390	0.489	0.477	0.466	0.455	0.446	0.436	0.427	0.418	0.410	0.401	0.393

TABLE 9 — *Continued*

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA LEVEL, CORRECTION IN INCHES ADDITIVE

Height in Feet, above Sea	Temperature of External Air — Degrees Fahrenheit										
	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
400	0.501	0.489	0.478	0.467	0.457	0.447	0.438	0.429	0.420	0.411	0.403
410	0.513	0.501	0.490	0.479	0.468	0.458	0.449	0.440	0.430	0.421	0.413
420	0.526	0.513	0.502	0.490	0.480	0.469	0.460	0.450	0.441	0.431	0.423
430	0.538	0.525	0.513	0.502	0.491	0.480	0.470	0.461	0.451	0.442	0.433
440	0.551	0.537	0.525	0.513	0.502	0.491	0.481	0.471	0.462	0.452	0.443
450	0.563	0.550	0.537	0.525	0.513	0.503	0.492	0.482	0.472	0.462	0.453
460	0.575	0.562	0.549	0.537	0.525	0.514	0.503	0.493	0.482	0.472	0.463
470	0.588	0.574	0.561	0.548	0.536	0.525	0.514	0.503	0.493	0.482	0.473
480	0.600	0.586	0.572	0.560	0.547	0.536	0.524	0.514	0.503	0.493	0.483
490	0.613	0.598	0.584	0.571	0.559	0.547	0.535	0.524	0.514	0.503	0.493
500	0.625	0.610	0.596	0.583	0.570	0.558	0.546	0.535	0.524	0.513	0.503
510	0.637	0.622	0.608	0.594	0.581	0.569	0.557	0.545	0.534	0.523	0.513
520	0.650	0.634	0.620	0.606	0.593	0.580	0.568	0.556	0.545	0.533	0.523
530	0.662	0.646	0.631	0.617	0.604	0.591	0.578	0.566	0.555	0.544	0.533
540	0.675	0.658	0.643	0.629	0.615	0.602	0.589	0.577	0.565	0.554	0.543
550	0.687	0.670	0.655	0.640	0.626	0.613	0.600	0.587	0.575	0.564	0.553
560	0.699	0.683	0.667	0.652	0.638	0.624	0.611	0.598	0.586	0.574	0.563
570	0.712	0.695	0.679	0.663	0.649	0.635	0.622	0.608	0.596	0.584	0.573
580	0.724	0.707	0.690	0.675	0.660	0.646	0.632	0.619	0.606	0.595	0.583
590	0.737	0.719	0.702	0.686	0.672	0.657	0.643	0.629	0.617	0.605	0.593
600	0.749	0.731	0.714	0.698	0.683	0.668	0.654	0.640	0.627	0.615	0.603
610	0.761	0.743	0.726	0.709	0.694	0.679	0.665	0.650	0.637	0.625	0.613
620	0.774	0.755	0.738	0.721	0.705	0.690	0.675	0.661	0.648	0.635	0.623
630	0.786	0.767	0.749	0.732	0.717	0.701	0.686	0.671	0.658	0.645	0.633
640	0.798	0.779	0.761	0.744	0.728	0.712	0.697	0.682	0.668	0.655	0.643
650	0.811	0.791	0.773	0.755	0.739	0.723	0.708	0.692	0.679	0.666	0.653
660	0.823	0.803	0.785	0.767	0.750	0.734	0.718	0.703	0.689	0.676	0.662
670	0.835	0.815	0.797	0.778	0.761	0.745	0.729	0.713	0.699	0.686	0.672
680	0.847	0.827	0.808	0.790	0.773	0.756	0.740	0.724	0.709	0.696	0.682
690	0.860	0.839	0.820	0.801	0.784	0.767	0.750	0.734	0.720	0.706	0.692
700	0.872	0.851	0.832	0.813	0.795	0.778	0.761	0.745	0.730	0.716	0.702
710	0.884	0.863	0.844	0.824	0.806	0.789	0.772	0.755	0.740	0.726	0.712
720	0.896	0.875	0.855	0.836	0.817	0.800	0.782	0.766	0.751	0.736	0.722
730	0.909	0.887	0.867	0.847	0.829	0.811	0.793	0.776	0.761	0.746	0.732
740	0.921	0.899	0.879	0.859	0.840	0.822	0.804	0.787	0.771	0.756	0.742
750	0.933	0.911	0.891	0.870	0.851	0.833	0.815	0.797	0.782	0.767	0.752
760	0.945	0.922	0.902	0.881	0.862	0.843	0.825	0.808	0.792	0.777	0.761
770	0.957	0.934	0.914	0.893	0.873	0.854	0.836	0.818	0.802	0.787	0.771
780	0.970	0.946	0.926	0.904	0.885	0.865	0.847	0.829	0.812	0.797	0.781
790	0.982	0.958	0.937	0.916	0.896	0.876	0.857	0.839	0.823	0.807	0.791

TABLE 9 — *Continued*

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA LEVEL, CORRECTION IN INCHES ADDITIVE

Height, in Feet, above Sea	Temperature of External Air — Degrees Fahrenheit										
	- 10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
800	0.994	0.970	0.949	0.927	0.907	0.887	0.868	0.850	0.833	0.817	0.801
810	1.006	0.982	0.961	0.938	0.918	0.898	0.878	0.860	0.843	0.827	0.811
820	1.018	0.994	0.972	0.950	0.929	0.909	0.889	0.871	0.854	0.837	0.821
830	1.031	1.006	0.984	0.961	0.940	0.920	0.900	0.881	0.864	0.847	0.831
840	1.043	1.018	0.995	0.973	0.951	0.931	0.911	0.892	0.874	0.857	0.841
850	1.055	1.030	1.007	0.984	0.962	0.942	0.922	0.902	0.885	0.867	0.851
860	1.067	1.041	1.019	0.995	0.974	0.952	0.932	0.913	0.895	0.877	0.860
870	1.079	1.053	1.030	1.007	0.985	0.963	0.943	0.923	0.905	0.887	0.870
880	1.092	1.065	1.042	1.018	0.996	0.974	0.954	0.934	0.915	0.897	0.880
890	1.104	1.077	1.053	1.030	1.007	0.985	0.964	0.944	0.925	0.907	0.890
900	1.116	1.089	1.065	1.041	1.018	0.996	0.975	0.955	0.936	0.917	0.900
910	1.128	1.101	1.077	1.052	1.029	1.007	0.986	0.965	0.946	0.927	0.910
920	1.140	1.113	1.088	1.064	1.040	1.018	0.996	0.976	0.956	0.937	0.920
930	1.152	1.125	1.100	1.075	1.051	1.029	1.007	0.986	0.967	0.947	0.929
940	1.164	1.137	1.111	1.086	1.062	1.040	1.017	0.997	0.977	0.957	0.939
950	1.177	1.149	1.123	1.098	1.074	1.051	1.028	1.007	0.987	0.967	0.949
960	1.189	1.160	1.135	1.109	1.085	1.061	1.039	1.017	0.997	0.977	0.959
970	1.201	1.172	1.146	1.121	1.096	1.072	1.049	1.028	1.007	0.987	0.969
980	1.213	1.184	1.158	1.130	1.107	1.083	1.060	1.038	1.018	0.997	0.978
990	1.225	1.196	1.169	1.143	1.118	1.094	1.070	1.049	1.028	1.007	0.988
1000	1.237	1.208	1.181	1.154	1.129	1.105	1.081	1.059	1.038	1.017	0.998
1010	1.249	1.220	1.192	1.165	1.140	1.116	1.092	1.069	1.048	1.027	1.008
1020	1.261	1.232	1.204	1.177	1.151	1.127	1.102	1.080	1.058	1.037	1.018
1030	1.273	1.243	1.215	1.188	1.162	1.137	1.113	1.090	1.069	1.047	1.027
1040	1.285	1.255	1.227	1.199	1.173	1.148	1.123	1.101	1.079	1.057	1.037
1050	1.298	1.267	1.238	1.211	1.184	1.159	1.134	1.111	1.089	1.067	1.047
1060	1.310	1.279	1.250	1.222	1.195	1.170	1.145	1.121	1.099	1.077	1.057
1070	1.322	1.291	1.261	1.233	1.206	1.181	1.155	1.132	1.109	1.087	1.067
1080	1.334	1.302	1.273	1.244	1.217	1.191	1.166	1.142	1.120	1.097	1.076
1090	1.346	1.314	1.284	1.256	1.228	1.202	1.176	1.153	1.130	1.107	1.086
1100	1.358	1.326	1.296	1.267	1.239	1.213	1.187	1.163	1.140	1.117	1.096
1110	1.370	1.338	1.307	1.278	1.250	1.224	1.198	1.173	1.150	1.127	1.106
1120	1.382	1.350	1.319	1.289	1.261	1.235	1.208	1.184	1.160	1.137	1.115
1130	1.394	1.361	1.330	1.301	1.272	1.245	1.219	1.194	1.170	1.147	1.125
1140	1.406	1.373	1.342	1.312	1.283	1.256	1.229	1.204	1.180	1.157	1.135
1150	1.418	1.385	1.353	1.323	1.294	1.267	1.240	1.215	1.191	1.167	1.145
1160	1.430	1.397	1.365	1.334	1.305	1.278	1.251	1.225	1.201	1.177	1.154
1170	1.442	1.409	1.376	1.345	1.315	1.289	1.261	1.235	1.211	1.187	1.164
1180	1.454	1.420	1.388	1.357	1.327	1.299	1.272	1.245	1.221	1.197	1.174
1190	1.466	1.432	1.399	1.368	1.338	1.310	1.282	1.256	1.231	1.207	1.183

TABLE 9 — *Continued*

FOR REDUCING OBSERVATIONS OF THE BAROMETER TO SEA LEVEL, CORRECTION IN INCHES ADDITIVE

Height, in Feet, above Sea	Temperature of External Air — Degrees Fahrenheit										
	−10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
1200	1.478	1.444	1.411	1.379	1.349	1.321	1.293	1.266	1.241	1.217	1.193
1210	1.490	1.456	1.422	1.390	1.360	1.332	1.303	1.276	1.251	1.227	1.203
1220	1.502	1.467	1.434	1.401	1.371	1.342	1.314	1.288	1.261	1.237	1.212
1230	1.514	1.479	1.445	1.413	1.382	1.353	1.324	1.297	1.271	1.247	1.222
1240	1.526	1.491	1.457	1.424	1.393	1.364	1.335	1.307	1.281	1.257	1.232
1250	1.538	1.502	1.468	1.435	1.404	1.374	1.345	1.317	1.291	1.266	1.242
1260	1.550	1.514	1.479	1.446	1.415	1.385	1.356	1.328	1.302	1.276	1.251
1270	1.562	1.526	1.491	1.457	1.426	1.396	1.366	1.338	1.312	1.286	1.261
1280	1.574	1.538	1.502	1.469	1.437	1.407	1.377	1.348	1.322	1.296	1.271
1290	1.586	1.549	1.514	1.480	1.448	1.417	1.387	1.359	1.332	1.306	1.280
1300	1.598	1.561	1.525	1.491	1.459	1.428	1.398	1.369	1.342	1.316	1.290
1310	1.610	1.573	1.536	1.502	1.470	1.439	1.408	1.379	1.352	1.326	1.300
1320	1.622	1.584	1.548	1.513	1.481	1.449	1.419	1.390	1.362	1.336	1.309
1330	1.634	1.596	1.559	1.525	1.492	1.460	1.429	1.400	1.372	1.346	1.319
1340	1.646	1.608	1.571	1.536	1.503	1.471	1.440	1.410	1.382	1.356	1.329
1350	1.658	1.620	1.582	1.547	1.514	1.482	1.450	1.420	1.393	1.366	1.339
1360	1.669	1.631	1.593	1.558	1.524	1.492	1.461	1.431	1.403	1.375	1.348
1370	1.681	1.643	1.605	1.569	1.535	1.503	1.471	1.441	1.413	1.385	1.358
1380	1.693	1.655	1.616	1.581	1.546	1.514	1.482	1.451	1.423	1.395	1.368
1390	1.705	1.666	1.628	1.592	1.557	1.524	1.492	1.462	1.433	1.405	1.377
1400	1.717	1.678	1.639	1.603	1.568	1.535	1.503	1.472	1.443	1.415	1.387
1410	1.729	1.690	1.650	1.614	1.579	1.546	1.513	1.482	1.453	1.425	1.397
1420	1.741	1.701	1.662	1.625	1.590	1.556	1.524	1.492	1.463	1.435	1.406
1430	1.753	1.713	1.673	1.636	1.601	1.567	1.534	1.503	1.473	1.444	1.416
1440	1.765	1.724	1.685	1.647	1.612	1.577	1.545	1.513	1.483	1.454	1.426
1450	1.777	1.736	1.696	1.658	1.623	1.588	1.555	1.523	1.493	1.464	1.436
1460	1.788	1.748	1.707	1.670	1.633	1.599	1.565	1.533	1.503	1.474	1.445
1470	1.800	1.759	1.719	1.681	1.644	1.609	1.576	1.543	1.513	1.484	1.455
1480	1.812	1.771	1.730	1.692	1.655	1.620	1.586	1.554	1.523	1.493	1.465
1490	1.824	1.782	1.742	1.703	1.666	1.630	1.597	1.564	1.533	1.503	1.474
1500	1.836	1.794	1.753	1.714	1.677	1.641	1.607	1.574	1.543	1.513	1.484

ELEVATION ABOVE SEA LEVEL OF THE GREAT LAKES

Lake Superior, 602 feet.	Lake Huron, 581 feet.
Lake Michigan, 581 feet.	Lake Erie, 573 feet.

Lake Ontario, 247 feet.

TABLE 10

VELOCITY OF SOUND IN METERS PER SECOND

Air	0° C.	331.4	Brass		3500
Hydrogen	0° C.	1286	Copper	20° C.	3560
Oxygen	0° C.	317	Glass		5000 to 6000
Carbon dioxide	0° C.	261	Iron	20° C.	5130
Water	8° C.	1435	Steel		5200

TABLE 11

SIZES AND NUMBERS OF STEEL MUSIC OR PIANO WIRE (ENGLISH)

No. of Gauge	Diameter in Inches	No. of Gauge	Diameter in Inches	No. of Gauge	Diameter in Inches
2	0.0105	11	0.0270	21	0.0445
3	0.0115	12	0.0285	22	0.0470
4	0.0125	13	0.0305	23	0.0490
5	0.0145	14	0.0320	24	0.0530
6	0.0150	15	0.0350	25	0.0560
7	0.0175	16	0.0360	26	0.0605
8	0.0190	17	0.0380	27	0.0640
9	0.0220	18	0.0400	28	0.0685
10	0.0245	19	0.0420	29	0.0715
		20	0.0430	30	0.0750

TABLE 12

INDICES OF REFRACTION (FOR THE *D* LINE)

Air	1.000294	Diamond	2.47 to 2.75
Alcohol, ethyl	1.361	Flint glass	1.57 to 1.71
Benzine	1.49	Glycerine	1.47
Canada balsam	1.54	Ice	1.310
Carbon disulphide	1.626	Water	1.332
Crown glass	1.5150		

TABLE 13

NATURAL SINES AND TANGENTS

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

TABLE 14

COEFFICIENT OF LINEAR EXPANSION

Aluminum	0.00002221	Lead	0.00002709
Brass	0.00001875	Silver	0.00001943
Copper	0.00001666	Steel, tempered	0.00001322
Iron, cast	0.00001125	Steel, untempered	0.00001095
Iron, wrought	0.00001220	Zinc	0.00002976

TABLE 15

SPECIFIC HEATS

Aluminum	0.2122	Lead	0.0315
Brass	0.086	Mercury	0.0335
Copper	0.0933	Nickel	0.1092
Ice	0.504	Silver	0.0559
Iron	0.1124	Zinc	0.0935
Glass	0.1770		

TABLE 16

TENSION OF WATER VAPOR IN MILLIMETERS OF MERCURY AT DIFFERENT TEMPERATURES C.

t° C.	mm.	t° C.	mm.	t° C.	mm.	t° C.	mm.	t° C.	mm.
– 10	2.2	5	6.5	20	17.4	55	117.4	98.6	722.7
– 9	2.3	6	7.0	21	18.5	60	148.7	98.7	725.3
– 8	2.5	7	7.5	22	19.6	65	186.9	98.8	727.9
– 7	2.7	8	8.0	23	20.9	70	232.9	98.9	730.5
– 6	2.9	9	8.5	24	22.2	75	288.3	99.0	733.2
– 5	3.2	10	9.1	25	23.5	80	354.4	99.1	735.8
– 4	3.4	11	9.8	26	25.0	85	432.7	99.2	738.5
– 3	3.7	12	10.4	27	26.5	90	525.5	99.3	741.1
– 2	3.9	13	11.1	28	28.1	95	633.7	99.4	743.8
– 1	4.2	14	11.9	29	29.7	98.0	707.1	99.5	746.5
0	4.6	15	12.7	30	31.5	98.1	709.7	99.6	749.2
1	4.9	16	13.5	35	41.9	98.2	712.3	99.7	751.9
2	5.3	17	14.4	40	54.9	98.3	714.9	99.8	754.6
3	5.7	18	15.3	45	71.4	98.4	717.4	99.9	757.3
4	6.1	19	16.3	50	92.0	98.5	720.0	100.	760.0

TABLE 17

Grams of Water Vapor contained in a Cubic Meter of Saturated Air at Different Temperatures C.

t° C.	g.	t° C.	g.	t° C.	g.	t° C.	g.	t° C.	g.
− 9	2.5	− 1	4.51	7	7.70	15	12.71	23	20.4
− 8	2.7	0	4.84	8	8.22	16	13.51	24	21.5
− 7	2.9	1	5.18	9	8.76	17	14.34	25	22.8
− 6	3.2	2	5.54	10	9.33	18	15.22	26	24.1
− 5	3.41	3	5.92	11	9.94	19	16.14	27	25.5
− 4	3.66	4	6.33	12	10.57	20	17.12	28	26.9
− 3	3.93	5	6.76	13	11.25	21	18.14	29	28.5
− 2	4.21	6	7.22	14	11.96	22	19.2	30	30.1

TABLE 18

Boiling Temperature *t* of Water for Different Barometric Pressures *b*. (From Regnault's observations.)

b mm.	t°	b mm.	t°	b mm.	t°	b mm.	t°	b mm.	t°
680	96.92	700	97.72	720	98.50	740	99.26	760	100.00
81	96.96	01	.76	21	.54	41	.30	61	.04
82	97.00	02	.80	22	.57	42	.33	62	.07
83	.05	03	.84	23	.61	43	.37	63	.11
84	.09	04	.88	24	.65	44	.41	64	.15
85	.13	05	.92	25	.69	45	.44	65	.18
86	.17	06	.96	26	.73	46	.48	66	.22
87	.21	07	97.99	27	.77	47	.52	67	.26
88	.25	08	98.03	28	.80	48	.56	68	.29
89	.29	09	.07	29	.84	49	.59	69	.33
690	97.32	710	98.11	730	98.88	750	99.63	770	100.36
691	97.36	711	98.15	731	98.92	751	99.67	771	100.40
92	.40	12	.19	32	.96	52	.71	72	.44
93	.44	13	.23	33	.99	53	.74	73	.47
94	.48	14	.27	34	99.03	54	.78	74	.51
95	.52	15	.31	35	.07	55	.82	75	.55
96	.56	16	.34	36	.11	56	.85	76	.58
97	.60	17	.38	37	.14	57	.89	77	.62
98	.64	18	.42	38	.18	58	.93	78	.65
699	.68	19	.46	39	.22	59	.96	79	.69
700	97.72	720	98.50	740	99.26	760	100.00	780	100.73

TABLE 19

TABLE OF PROPORTIONAL PARTS FOR USE WITH THE WHEATSTONE SLIDE-WIRE BRIDGE

The table gives the value of $a \div (100 - a)$ for all values of a from 0.1 cm. to 99.9 cm. (See Figure 66, page 159, and formula, page 160.)

a	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
00	0.0000	0010	0020	0030	0040	0050	0060	0071	0081	0091
01	0101	0111	0122	0132	0142	0152	0163	0173	0183	0194
02	0204	0215	0225	0235	0246	0256	0267	0278	0288	0299
03	0309	0320	0331	0341	0352	0363	0373	0384	0395	0406
04	0417	0428	0438	0449	0460	0471	0482	0493	0504	0515
05	0526	0537	0549	0560	0571	0582	0593	0605	0616	0627
06	0638	0650	0661	0672	0684	0695	0707	0718	0730	0741
07	0753	0764	0776	0788	0799	0811	0823	0834	0846	0858
08	0870	0881	0893	0905	0917	0929	0941	0953	0965	0977
09	0989	1001	1013	1025	1038	1050	1062	1074	1087	1099
10	0.1111	1124	1136	1148	1161	1173	1186	1198	1211	1223
11	1236	1249	1261	1274	1287	1299	1312	1325	1338	1351
12	1364	1377	1390	1403	1416	1429	1442	1455	1468	1481
13	1494	1508	1521	1534	1547	1561	1574	1588	1601	1614
14	1628	1641	1655	1669	1682	1696	1710	1723	1737	1751
15	1765	1779	1793	1806	1820	1834	1848	1862	1877	1891
16	1905	1919	1933	1947	1962	1976	1990	2005	2019	2034
17	0.2048	2063	2077	2092	2107	2121	2136	2151	2166	2180
18	2195	2210	2225	2240	2255	2270	2285	2300	2315	2331
19	2346	2361	2376	2392	2407	2422	2438	2453	2469	2484
20	2500	2516	2531	2547	2563	2579	2595	2610	2626	2642
21	2658	2674	2690	2707	2723	2739	2755	2771	2788	2804
22	2821	2837	2854	2870	2887	2903	2920	2937	2953	2970
23	2987	3004	3021	3038	3055	3072	3089	3106	3123	3141
24	0.3158	3175	3193	3210	3228	3245	3263	3280	3298	3316
25	3333	3351	3369	3387	3405	3423	3441	3459	3477	3495
26	3514	3532	3550	3569	3587	3605	3624	3643	3661	3680
27	3699	3717	3736	3755	3774	3793	3812	3831	3850	3870
28	3889	3908	3928	3947	3967	3986	4006	4025	4045	4065
29	0.4085	4104	4124	4144	4164	4184	4205	4225	4245	4265
30	4286	4306	4327	4347	4368	4389	4409	4430	4451	4472
31	4493	4514	4535	4556	4577	4599	4620	4641	4663	4684
32	4706	4728	4749	4771	4793	4815	4837	4859	4881	4903
33	4925	4948	4970	4993	5015	5038	5060	5083	5106	5129
34	0.5152	5175	5198	5221	5244	5267	5291	5314	5337	5361
35	5385	5408	5432	5456	5480	5504	5528	5552	5576	5601
36	5625	5650	5674	5699	5723	5748	5773	5798	5823	5848
37	5873	5898	5924	5949	5974	6000	6026	6051	6077	6103
38	0.6129	6155	6181	6208	6234	6260	6287	6313	6340	6367
39	6393	6420	6447	6475	6502	6529	6556	6584	6611	6639
40	6667	6695	6722	6750	6779	6807	6835	6863	6892	6921
41	6949	6978	7007	7036	7065	7094	7123	7153	7182	7212
42	0.7241	7271	7301	7331	7361	7391	7422	7452	7483	7513
43	7544	7575	7606	7637	7668	7699	7731	7762	7794	7825
44	7857	7889	7921	7953	7986	8018	8051	8083	8116	8149
45	0.8182	8215	8248	8282	8315	8349	8382	8416	8450	8484
46	8519	8553	8587	8622	8657	8692	8727	8762	8797	8832
47	8868	8904	8939	8975	9011	9048	9084	9121	9157	9194
48	0.9231	9268	9305	9342	9380	9418	9455	9493	9531	9570
49	9608	9646	9685	9724	9763	9802	9841	9881	9920	9960

TABLE 19 — *Continued*

a	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
50	1.000	1.004	1.008	1.012	1.016	1.020	1.024	1.028	1.033	1.037
51	1.041	1.045	1.049	1.053	1.058	1.062	1.066	1.070	1.075	1.079
52	1.083	1.088	1.092	1.096	1.101	1.105	1.110	1.114	1.119	1.123
53	1.128	1.132	1.137	1.141	1.146	1.151	1.155	1.160	1.165	1.169
54	1.174	1.179	1.183	1.188	1.193	1.198	1.203	1.208	1.212	1.217
55	1.222	1.227	1.232	1.237	1.242	1.247	1.252	1.257	1.262	1.268
56	1.273	1.278	1.283	1.288	1.294	1.299	1.304	1.309	1.315	1.320
57	1.326	1.331	1.336	1.342	1.347	1.353	1.358	1.364	1.370	1.375
58	1.381	1.387	1.392	1.398	1.404	1.410	1.415	1.421	1.427	1.433
59	1.439	1.445	1.451	1.457	1.463	1.469	1.475	1.481	1.488	1.494
60	1.500	1.506	1.513	1.519	1.525	1.532	1.538	1.545	1.551	1.558
61	1.564	1.571	1.577	1.584	1.591	1.597	1.604	1.611	1.618	1.625
62	1.632	1.639	1.646	1.653	1.660	1.667	1.674	1.681	1.688	1.695
63	1.703	1.710	1.717	1.725	1.732	1.740	1.747	1.755	1.762	1.770
64	1.778	1.786	1.793	1.801	1.809	1.817	1.825	1.833	1.841	1.849
65	1.857	1.865	1.874	1.882	1.890	1.899	1.907	1.915	1.924	1.933
66	1.941	1.950	1.959	1.967	1.976	1.985	1.994	2.003	2.012	2.021
67	2.030	2.040	2.049	2.058	2.067	2.077	2.086	2.096	2.106	2.115
68	2.125	2.135	2.145	2.155	2.165	2.175	2.185	2.195	2.205	2.215
69	2.226	2.236	2.247	2.257	2.268	2.279	2.289	2.300	2.311	2.322
70	2.333	2.344	2.356	2.367	2.378	2.390	2.401	2.413	2.425	2.436
71	2.448	2.460	2.472	2.484	2.497	2.509	2.521	2.534	2.546	2.559
72	2.571	2.584	2.597	2.610	2.623	2.636	2.650	2.663	2.676	2.690
73	2.704	2.717	2.731	2.745	2.759	2.774	2.788	2.802	2.817	2.831
74	2.846	2.861	2.876	2.891	2.906	2.922	2.937	2.953	2.968	2.984
75	3.000	3.016	3.032	3.049	3.065	3.082	3.098	3.115	3.132	3.149
76	3.167	3.184	3.202	3.219	3.237	3.255	3.274	3.292	3.310	3.329
77	3.348	3.367	3.386	3.405	3.425	3.444	3.464	3.484	3.505	3.525
78	3.545	3.566	3.587	3.608	3.630	3.651	3.673	3.695	3.717	3.739
79	3.762	3.785	3.808	3.831	3.854	3.878	3.902	3.926	3.950	3.975
80	4.000	4.025	4.051	4.076	4.102	4.128	4.155	4.181	4.208	4.236
81	4.263	4.291	4.319	4.348	4.376	4.405	4.435	4.465	4.495	4.525
82	4.556	4.587	4.618	4.650	4.682	4.714	4.747	4.780	4.814	4.848
83	4.882	4.917	4.952	4.988	5.024	5.061	5.098	5.135	5.173	5.211
84	5.250	5.289	5.329	5.369	5.410	5.452	5.494	5.536	5.579	5.623
85	5.667	5.711	5.757	5.803	5.849	5.897	5.944	5.993	6.042	6.092
86	6.143	6.194	6.246	6.299	6.353	6.407	6.463	6.519	6.576	6.634
87	6.692	6.752	6.813	6.874	6.937	7.000	7.065	7.130	7.197	7.264
88	7.333	7.403	7.475	7.547	7.621	7.696	7.772	7.850	7.929	8.009
89	8.091	8.174	8.259	8.346	8.434	8.524	8.615	8.709	8.804	8.901
90	9.000	9.101	9.204	9.309	9.417	9.526	9.638	9.753	9.870	9.989
91	10.11	10.24	10.36	10.49	10.63	10.77	10.90	11.05	11.20	11.35
92	11.50	11.66	11.82	11.99	12.16	12.33	12.51	12.70	12.89	13.08
93	13.29	13.49	13.71	13.93	14.15	14.38	14.63	14.87	15.13	15.39
94	15.67	15.95	16.24	16.54	16.86	17.18	17.52	17.87	18.23	18.61
95	19.00	19.41	19.83	20.28	20.74	21.22	21.73	22.26	22.81	23.39
96	24.00	24.64	25.32	26.03	26.78	27.57	28.41	29.30	30.25	31.26
97	32.33	33.48	34.71	36.04	37.46	39.00	40.67	42.48	44.45	46.62
98	49.00	51.6	54.6	57.8	61.5	65.7	70.4	75.9	82.3	89.9
99	99.0	110	124	142	166	199	249	332	499	999

TABLE 20

SIZE, ETC., OF COPPER WIRE. B. & S. GAUGE

Gauge No.	Size				Weight		Resistance at 24° C.	
	Diameter		Square of Diameter in Mils.	Area in Sq. In.	Pounds per 1000 Ft.	Feet per Pound	Ohms per 1000 Ft.	Ohms per Pound
	Mils.	Millim.						
0000	460.00	11.684	211600.0	.166191	639.33	1.56	.051	.0000798
000	409.64	10.405	167805.0	.131790	507.01	1.97	.064	.000127
00	364.80	9.266	133079.4	.104590	402.09	2.49	.081	.000202
0	324.95	8.254	105592.5	.082932	319.04	3.13	.102	.000320
1	289.30	7.348	83694.2	.065733	252.88	3.95	.129	.00051
2	257.63	6.544	66373.0	.052130	200.54	4.99	.163	.000811
3	229.42	5.827	52634.0	.041339	159.03	6.29	.205	.001288
4	204.31	5.189	41742.0	.032784	126.12	7.93	.259	.00205
5	181.94	4.621	33102.0	.025998	100.01	10.00	.326	.00326
6	162.02	4.115	26250.5	.020617	79.32	12.61	.411	.00518
7	144.28	3.665	20816.0	.016349	62.90	15.90	.519	.00824
8	128.49	3.264	16509.0	.012766	49.88	20.05	.654	.01311
9	114.43	2.907	13094.0	.010284	39.56	25.28	.824	.02083
10	101.89	2.588	10381.0	.008153	31.37	31.88	1.040	.03314
11	90.74	2.305	8234.0	.006467	24.88	40.20	1.311	.05269
12	80.81	2.053	6529.9	.005129	19.73	50.69	1.653	.08377
13	71.96	1.828	5178.4	.004067	15.65	63.91	2.084	.13321
14	64.01	1.628	4106.8	.003147	12.41	80.59	2.628	.2118
15	57.07	1.450	3256.7	.002558	9.84	101.63	3.314	.3368
16	50.82	1.291	2582.9	.002029	7.81	128.14	4.179	.5355
17	45.26	1.150	2048.2	.001609	6.19	161.59	5.269	.8515
18	40.30	1.024	1624.3	.001276	4.91	203.76	6.645	1.3536
19	35.89	.899	1252.4	.000984	3.78	264.26	8.617	2.2772
20	31.96	.812	1021.5	.000802	3.09	324.00	10.566	3.423
21	28.46	.723	810.1	.000636	2.45	408.56	13.323	5.443
22	25.35	.644	642.7	.000505	1.94	515.15	16.799	8.654
23	22.57	.573	509.5	.000400	1.54	649.66	21.185	13.763
24	20.10	.511	404.0	.000317	1.22	819.21	26.713	21.885
25	17.90	.455	320.4	.000252	.97	1032.96	33.684	34.795
26	15.94	.405	254.0	.000199	.77	1302.61	42.477	55.331
27	14.19	.361	201.5	.000158	.61	1642.55	53.563	87.979
28	12.64	.321	159.8	.000125	.48	2071.22	67.542	139.893
29	11.26	.286	126.7	.000100	.38	2611.82	85.170	222.449
30	10.03	.255	100.5	.000079	.30	3293.97	107.391	353.742
31	8.93	.227	79.7	.000063	.24	4152.22	135.402	562.221
32	7.95	.202	63.2	.000050	.19	5236.66	170.765	894.242
33	7.08	.180	50.1	.000039	.15	6602.71	215.312	1421.646
34	6.30	.160	39.7	.000031	.12	8328.30	271.583	2261.82
35	5.61	.143	31.5	.000025	.10	10501.35	342.443	3596.10
36	5.00	.127	25.0	.000020	.08	13238.83	431.712	5715.36
37	4.45	.113	19.8	.000016	.06	16691.06	544.287	9084.71
38	3.96	.101	15.7	.000012	.05	20854.65	686.511	14320.3
39	3.53	.090	12.5	.000010	.04	26302.23	865.016	22752.6
40	3.14	.080	9.9	.000008	.03	33175.94	1091.865	36223.6

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